Fibre preparation for spinning

Short Staple Processing

Introduction

Short staple fibres(短纤维) refer to fibres less than 2 inches in length. Cotton is a typical example of short staple fibre. The short staple system(短纤维纺纱系统) is used to proces cotton mainly, cotton/polyester(涤纶) blends are the next most commonly processed fibres on the short staple system Other fibres, such as viscose(粘胶), are also processed occasionally using the system. Short staple yarns make up the bulk of international yarn market.

Since cotton is the dominant fibres used, the emphasis of this topic will be on cotton processing. The actual spinning of yarns is discussed in a separate module.

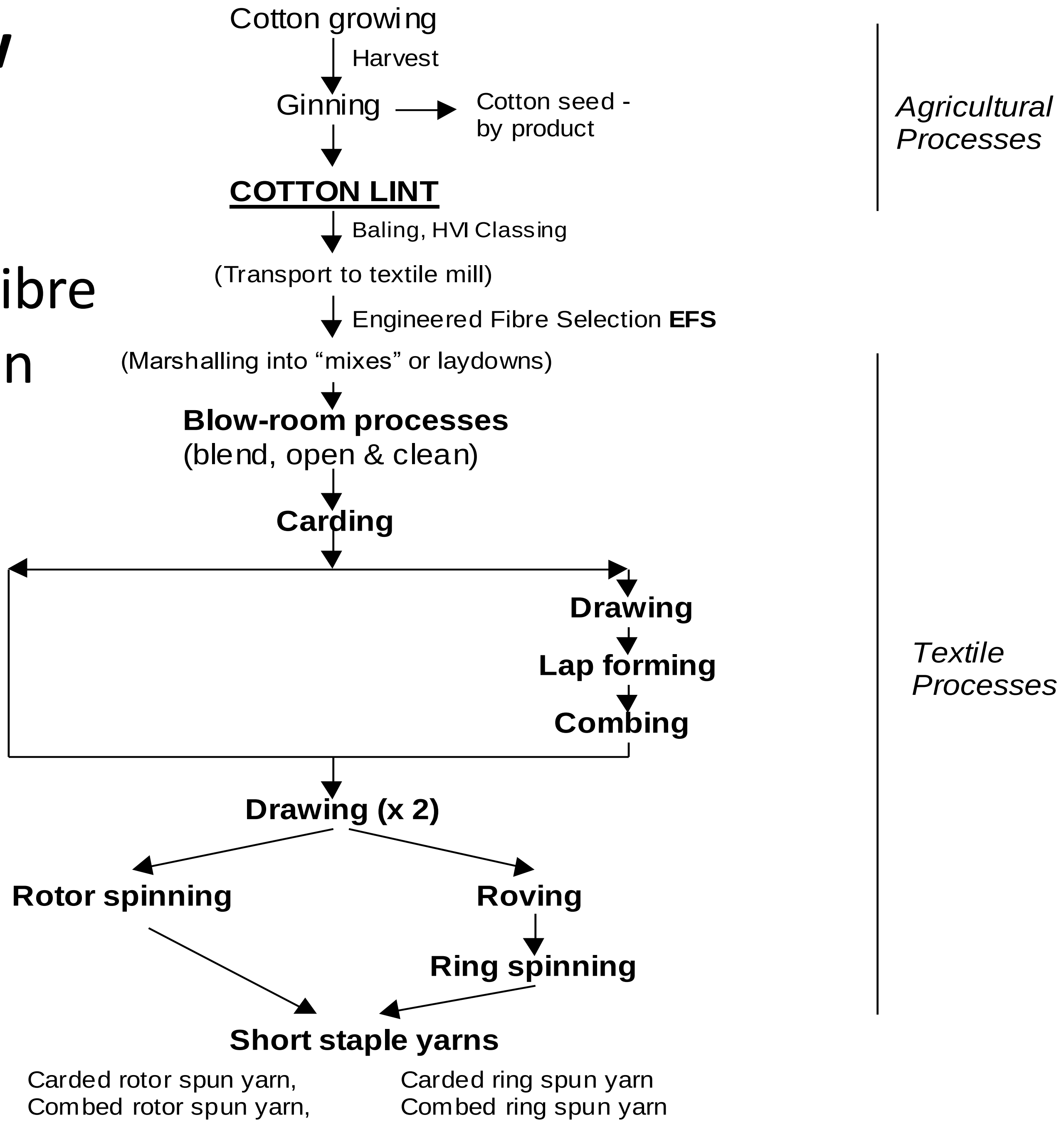
Objectives

At the end of this topic you should be able to:

- Know the flow chart of cotton processing
- Understand the principles and objectives of carding, drawing, and combing
- Appreciate the differences in the process and property of carded ring spun yarn(环锭纺粗梳纱), combed ring spun yarn(环锭纺精梳纱), carded rotor spun yarn(转杯纺粗梳纱), and combed rotor spun yarn(转杯纺精梳纱).

Process overview

The process flow chart for cotton processing from fibre to yarn is shown in Figure 1.1.



Cotton growing

Harvest

Ginning

Cotton seed - by product

COTTON LINT

Baling, HVI Classing

(Transport to textile mill)

Engineered Fibre Selection **EFS**

(Marshalling into “mixes” or laydowns)

Blow-room processes
(blend, open & clean)

Carding

Drawing

Lap forming

Combing

Drawing (x 2)

Rotor spinning

Roving

Ring spinning

Short staple yarns

Carded rotor spun yarn,
Combed rotor spun yarn,

Carded ring spun yarn
Combed ring spun yarn

Agricultural Processes

Textile Processes

Fig. 1.1: Fibre to yarn processing for cotton

The agricultural processes include cotton growing, harvesting and ginning(轧棉). Cotton grown in different regions have different properties. Modern cotton harvesting uses machine pickers or strippers. Since cotton fibres do not mature at the same time and machine picking is less discriminative than traditional hand picking, large quantities of impurities such as green bolls, leaf, stick, and trash are also picked up during cotton harvesting, together with the seed cotton.

On a weight basis, “seed cotton” contains approximately 35% fibre (lint), 55% seed, and 10% trash. Obviously the cotton seed and other impurities need to be removed from the fibres. This is largely done in a gin, which removes all green balls and cotton seeds, about 95% burrs, 92% sticks, and about 85% fine trash.

The actual process (in a gin) that separates cotton fibres and the seed they grow attached to is called ginning. Other machines are also used before and after ginning to mechanically clean the fibres. The ginned cotton is now known as cotton lint or lint cotton. The fibres in the cotton lint vary considerably in length because of fibre breakage caused by the severe mechanical actions during ginning and cleaning. The cotton lint is then sampled and packed into bales weighing 227 kg (or 500 pounds), containing over 60 billion individual fibres.

Fibre samples are now tested on the High Volume Instrument (HVI) for a range of fibre properties, including strength, elongation, length, uniformity, micronaire, colour, and trash. The HVI system was developed in the late 1960s and has been increasingly accepted since the 1980s. Before the introduction of the HVI system, cotton in a bale was graded subjectively by experienced cotton classers for properties such as staple length, colour, and trash content.

The results were then used to assign cotton bales into lots or categories. When the cotton was ready for consumption, the bales were grouped into mixes or laydowns. Bales from different regions were mixed in proportion to the number of bales in each lot and fed into the opening line machinery in the blow-room.

Today, objective measurement is widely used. When the bales arrive at a textile mill to start the textile processes, the test results are used as a basis for fibre selection and mixing according to the end product requirements. The modern cotton mill will "engineer" its yarn to meet specific end-use requirements. The engineered fibre selection (EFS) system, introduced by Cotton Inc. (USA) in 1982, has been used increasingly by cotton mills to facilitate this important task.

It is most useful in bale management, particularly for storing and retrieving bales, for selecting bales with fibre properties within specified ranges and average values, for composing consistent bale laydowns and for predicting yarn strength and other yarn properties based on tailer-made regression analyses. The bulk of the cotton bales consumed in America is now managed at the mill level by the engineered fibre selection system (EFS).

Adequate fibre blending and mixing is also vital to ensure processing efficiency and yarn quality. The cotton lint still contains some small trash particles, which have to be removed by the textile processes, such as carding and combing. The textile processes also perform fibre opening, fibre alignment, fibre mixing and attenuation to get the fibres ready for spinning. As indicated in Figure 1.1, depending on the particular processing route followed, four major types of cotton yarn may be produced – carded rotor spun, carded ring spun, combed rotor spun, combed ring spun.

An overview of the key stages is given in Table 1.1.

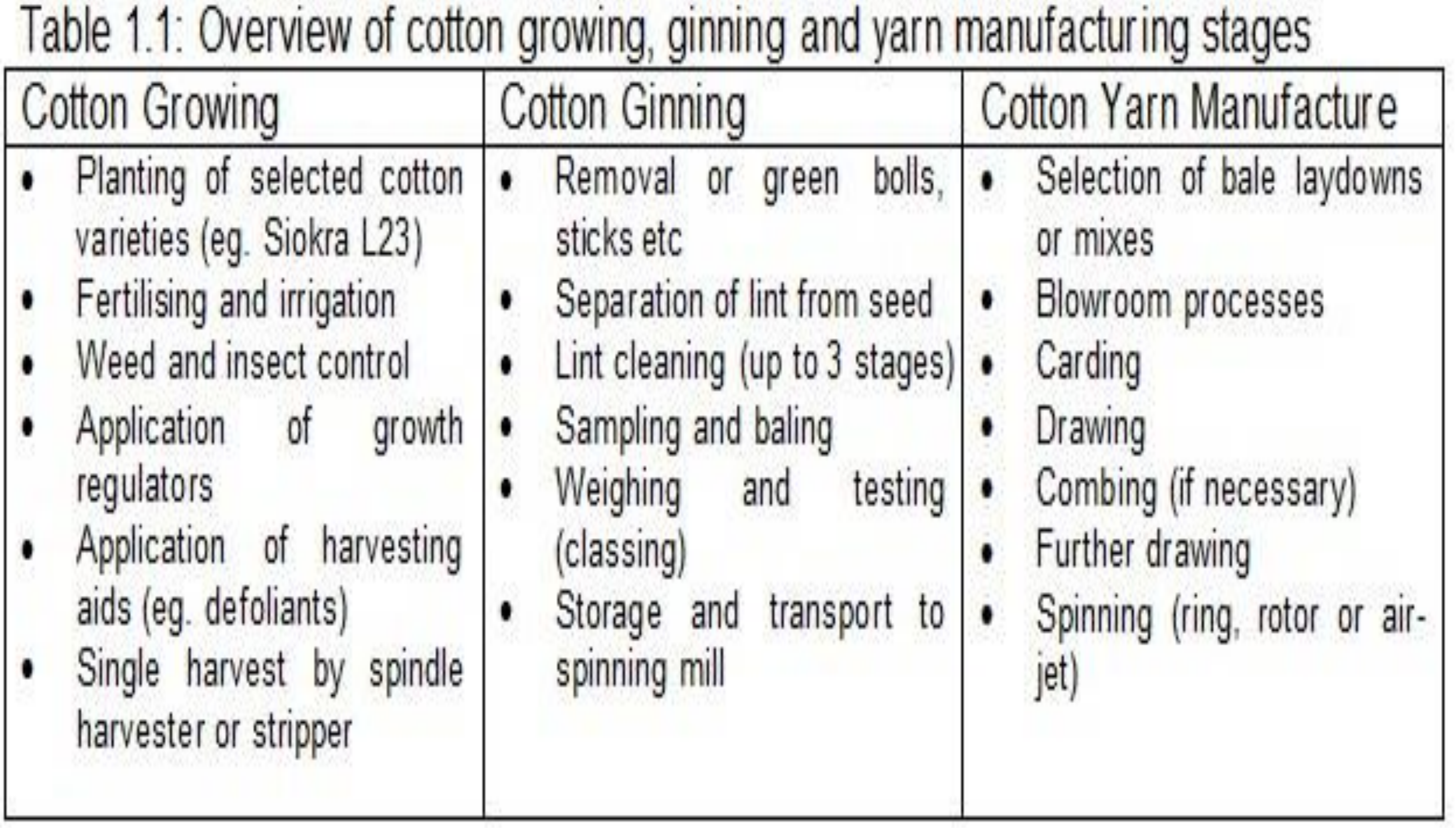


Table 1.1: Overview of cotton growing, ginning and yarn manufacturing stages

Cotton Growing	Cotton Ginning	Cotton Yarn Manufacture
• Planting of selected cotton varieties (eg. Siokra L23) • Fertilising and irrigation • Weed and insect control • Application of growth regulators • Application of harvesting aids (eg. defoliants) • Single harvest by spindle harvester or stripper	• Removal or green bolls, sticks etc • Separation of lint from seed • Lint cleaning (up to 3 stages) • Sampling and baling • Weighing and testing (classing) • Storage and transport to spinning mill	• Selection of bale laydowns or mixes • Blowroom processes • Carding • Drawing • Combing (if necessary) • Further drawing • Spinning (ring, rotor or air-jet)

It is important to keep in mind at this stage that before fibres can be made into useful yarns, they should be:

- Free from impurities
- Well individualised and aligned
- Well mixed
- Of adequate length and strength

Knowing these requirements will help us understand why the fibres need to go through many textile processes before the actual spinning process. For instance, in order to remove impurities imbedded in fibres, we need to open the fibres first to expose those impurities. Fibre opening needs to be gradually carried out so as not to stress and damage the fibres too much. In fact, there are two opening stages:

Stage 1: Breaking apart (break large tufts of fibres into small tufts)

Stage 2: Opening out (open small tufts into individual fibres)

Individualising the fibres is very important. As mentioned in the module on yarn evenness, poorly separated fibres will travel in groups during drafting, which will lead to reduced evenness and increased imperfections in the final yarn. For a yarn to have adequate strength, fibres in the yarn should be well aligned in order to share the applied load on the yarn. The different degrees of fibre alignment in different yarns often explain the differences in yarn properties.

Because of the variability that exists both within and between fibres, fibres should be well mixed before the actual spinning stage. There are two basic requirements for a good fibre mix or blend:

Requirement 1: The blend (mix) is homogenous

Requirement 2: The blend (mix) is intimate

The first requirement entails that different fibres are mixed in the right proportion, while the second requirement can only be achieved with different individual fibres lying side by side.

Preserving the quality of fibres during processing is also essential to ensure yarn quality. Damage to fibre length and strength will lead to reduced yarn strength.

With this overall picture in mind, we can now discuss the individual textile processes applied to fibres.

- **Objectives**

The blowroom is the section of a cotton spinning mill where the preparatory processes of opening, blending and cleaning are carried out. The blowroom machines blend, open and clean the ginned cotton before feeding it to the cotton card.

The ginned cotton, still contaminated with some impurities, arrives in the textile mill in compressed bales, fibre properties often vary from bale to bale. Blending is regarded as the most important process in a cotton spinning mill. It reduces variation of fibre characteristics, permits uniform processing and improves yarn quality. In the blending process, different cottons of known physical properties are combined to give a mix with the required or pre-determined average characteristics.

For example, the general formula for calculating the theoretical fineness (micronaire, μg/in.) is as follows

$$F_b = \frac{W_t}{\frac{W_1}{F_1} + \frac{W_2}{F_2} + \ldots.. + \frac{W_n}{F_n}} = \frac{Wt}{\Sigma \frac{W}{F}}$$

where F_b is the fineness of a blend of n components; Wt is the total weight of the blend; and W is the weight of any one component and F is its fineness. In terms of weight percentages, the above equation becomes:

$$F_b = \frac{100}{\frac{P_1}{F_1} + \frac{P_2}{F_2} + \ldots.. + \frac{P_n}{F_n}} = \frac{100}{\Sigma \frac{P}{F}}$$

where P is the percentage by weight of any one component and F is its fineness.

The group of different bales to be mixed is referred to as the "laydown", with laydowns containing between 10 and 100 bales. In a modern cotton spinning mill, automatic bale pluckers are used to extract and blend fibres from the laydowns. The bale plucker extracts, at controlled rates, small tufts of cotton from each bale (in the laydown) and delivers the fibres through pneumatic ducting (hence the name “blow-room”) to the subsequent opening and cleaning machines.

In the opening and cleaning processes, clumps of fibres from the bale plucker are opened to smaller tufts to facilitate further processing and to allow removal of impurities, such as dust, sand, seed particles, leaf and stem fragments and motes (undeveloped seeds). A number of machines are employed to perform the opening and cleaning actions gradually, so as not to cause too much fibre damage. In other words, the opening action in blow-room is largely the “breaking apart” stage mentioned in the previous section.

“Opening-out” or individualising the fibres is not intended in the blow-room. But some fibre damage is inevitable. In addition, the opening processes also create neps, or highly entangled fibres. At the end of the blowroom processes, the opened and cleaned cotton fibres are condensed in a lap form to feed into the carding process.

- **Blowroom installations**

In a typical blowroom installation, six distinguishable zones can be identified as indicated in figure 1.2. These are:

ZONE 1 - Bale opening
ZONE 2 - Coarse blending
ZONE 3 - Blending (Mixing)
ZONE 4 - Fine cleaning and dust removal
ZONE 5 - Intensive opening/cleaning (optional)
ZONE 6 - Card feed

If the cotton contains only few impurities, then the zone of intensive cleaning is not necessary.

Figure 1.2 Operating zones in a typical blowroom (Klein 1987a, p.13)

The zone 1 opening machine is usually an automatic bale plucker, an example of which is given in figure 1.3. As mentioned in the previous section, the bale plucker extracts, at controlled rates, small tufts of cotton from different bales in the laydown and delivers the fibres through pneumatic ducting to the subsequent opening and cleaning machines.

Figure 1.3 An automatic bale opening machine (Fritz and Cant 1986, p.327, courtesy of Rieter Machine Works)

The zone 2 coarse cleaning (and opening) machine is usually a step cleaner (figure 1.4) or a dual roller cleaner (figure 1.5). Both cleaners feature widely spaced striker elements working on fibres in relatively free flight. So the action on fibres are gentle.

Figure 1.4 A step cleaner (Shrigley 1973, p91)

For the step cleaner, fibres enter through the entry point (A). They are worked on by a series of 6 inclined beaters (B, D), under which is fitted a grid-bar system (C). The grid bars support the upward flow of fibres while allowing impurities to fall through into the trash box (F). The action of opposing spikes between adjacent beaters helps opening fibres and dislodging impurities. The baffle plates (E) prevent the beaters from creating a circular air current by deflecting the air and fibre to the next beater. The coarsely cleaned fibres come out the step cleaner through exit (G).

Figure 1.5 A dual-roller cleaning (Shrigley 1973, p93)

The dual-roller cleaner, shown in figure 1.5, has two spiked rollers (beaters A and B) mounted horizontally, with grid bars beneath each beater. A condenser fan downstream the cleaner draws fibres through the machine by suction. Fibres are opened by the spikes gradually. As can be seen from figure 1.5, the outlet is positioned higher than the inlet, ensuring that only the relatively small and light tufts of fibres can fly straight through. The residence time of fibre materials within the machine can be adjusted by the baffle plate D.

An example of zone 3 blending machine is shown in figure 1.6. This machine comprises several adjacent chambers into which the fibres are blown from above. The chambers are filled successively, but the fibre material is removed from all chambers simultaneously. This gives good long-term mixing.

Figure 1.6: The Hergeth Hollingsworth multiple mixer (Klein 1987a, p.19)

Fine cleaning requires further opening of fibres to expose the impurities. For this reason, finer opening elements are used.

Dust removal is not confined to one particular zone. But fine dust can only be effectively removed when the fibres are relatively open. Dust removal equipment is usually incorporated into the pneumatic ducting system, with the dust separated from fibre by air suction through perforated surfaces. The principle of a condenser type dust extractor is shown in figure 1.7. The condenser also helps even the flow of fibres, because the thin spots in the fibre sheet laying on the perforated screen will allow more air to flow, hence carrying more fibres to the thin spots.

Figure 1.7: Sketch of a condenser type dust extracter (Lord 1981, p.137)

Finally, the opened and cleaned fibres are fed to a card through a chute feed device. An example of a chute feed is shown in figure 1.8. It is vital that a uniform sheet of fibres be fed to the card. For this reason, chute feeds have control systems to ensure fibres are uniformly packed inside the chute.

Figure 1.8: An example of a chute feed (Lord 1981, p.138)

Cotton carding

- **Objectives**

  An old spinning mill adage states that "well carded is half spun". Card is also referred to as the heart of a spinning mill. This highlights the importance of the carding process. The main objectives of carding are:

  - Fibre opening/individualising
  - Fibre cleaning
  - Fibre mixing
  - Fibre aligning
  - Sliver forming

Understanding how a card achieves these objectives requires knowledge of its operating principle. Figure 1.9 shows a diagram of a modern high performance flat-top card.

1 – pneumatic duct
2 – feed chute
3 – transport roller
4 – card feed device
5 – taker-in or licker-in
6 – cleaning devices (grid bars etc)
7 – suction duct
8 – main cylinder
9 – extra carding bars
10 – flats
11 – cleaning unit
12 – extra carding bars
13 – under grids
14 – doffer
15 – stripping device
16 – calender rolls
17 – sliver can
18 – sliver coiler

Fig. 1.9: Diagram of a modern flat-top card (Klein 1987a, p.34.).

Fibres from the blow-room are supplied pneumatically via pipe ducting (1) to the feed chute (2) of the card. An evenly compressed fibre batt of about 500 – 900 ktex (g/m) is formed in the chute. A transport roller (3) forwards fibres from this matt to the card’s feed device (4), consisting of a feed roller and a feed plate. The licker-in or taker-in (5), covered with strong metal teeth, snatches fibres from the feed device, dislodges heavy impurities via the gaps of grid segments (6), and carries the fibres to the main cylinder (8). The suction ducts (7) carry away the dislodged impurities. The sawtooth elements (or clothing elements) on the main cylinder (8), which has a higher surface speed than the taker-in, strip the fibres off the taker-in (5) and carry them to the main carding zone between the cylinder (8) and the flats (10) (hence the name ‘flat-top’ card).

The flats comprise some 80 – 120 carding bars combined into a band moving on an endless path. When in the carding zone, the teeth on the carding bars and that on the main cylinder act together to repeatedly tear apart fibres into individual ones, to remove neps (highly entangled fibres) and some impurities. As the ‘action’ carding bars emerge from the carding zone, a cleaning unit (11) strips fibres, neps and impurities from the bars, and the bars then return for further action in the carding zone. Obviously, the main carding zone is where most of the card’s objectives are achieved. Extra carding bars (9, 12) are also used to increase the level of fibre opening in carding. The underside of the main cylinder is enclosed by grids or cover plates (13).

Fibres coming out of the main carding zone are individualised and aligned. They are carried by the teeth on the main cylinder to meet the teeth on the doffer (14), which has a slower surface speed than the cylinder. The doffer snatches some (not all) fibres from the cylinder surface and combines the fibres into a web because of its substantially lower surface speed relative to the main cylinder. Fibres not snatched by the doffer continue to travel with the main cylinder. These fibres are called “recycling fibres”. The recycling fibres will soon meet with “fresh fibres” from the taker-in and together these fibres are worked on in the main carding zone.

This is how fibre mixing is achieved in carding. In fact, carding is the only process where intimate mixing can be achieved. A fibre may go around the main cylinder many times and get mixed with many fresh fibres before it is finally removed by the doffer. The stripping device (15) then removes the fibre web from the doffer. The web is brought together as a sliver and compressed by a pair of calender rolls (16). Finally, the coiler (18) deposits the sliver into a sliver can (17).

The carding action of a flat-top card like this is quite intensive, and may cause considerable fibre damage and breakage, particularly for long fibres. For this reason, flat-top card is not used to card long fibres such as wool. Carding also creates some neps, or highly entangled fibres. While carding is supposed to align and straighten individual fibres, most fibres in a carded sliver have hooked ends. The reason for this will be discussed later.

- **Card clothing**

The tern 'card clothing' refers to the large number of pins or teeth covering the surfaces of various rollers on the card. There are three major types of card clothing - flexible fillet wire, semi-rigid wire, and metallic sawtooth wire, as shown in figure 1.10.

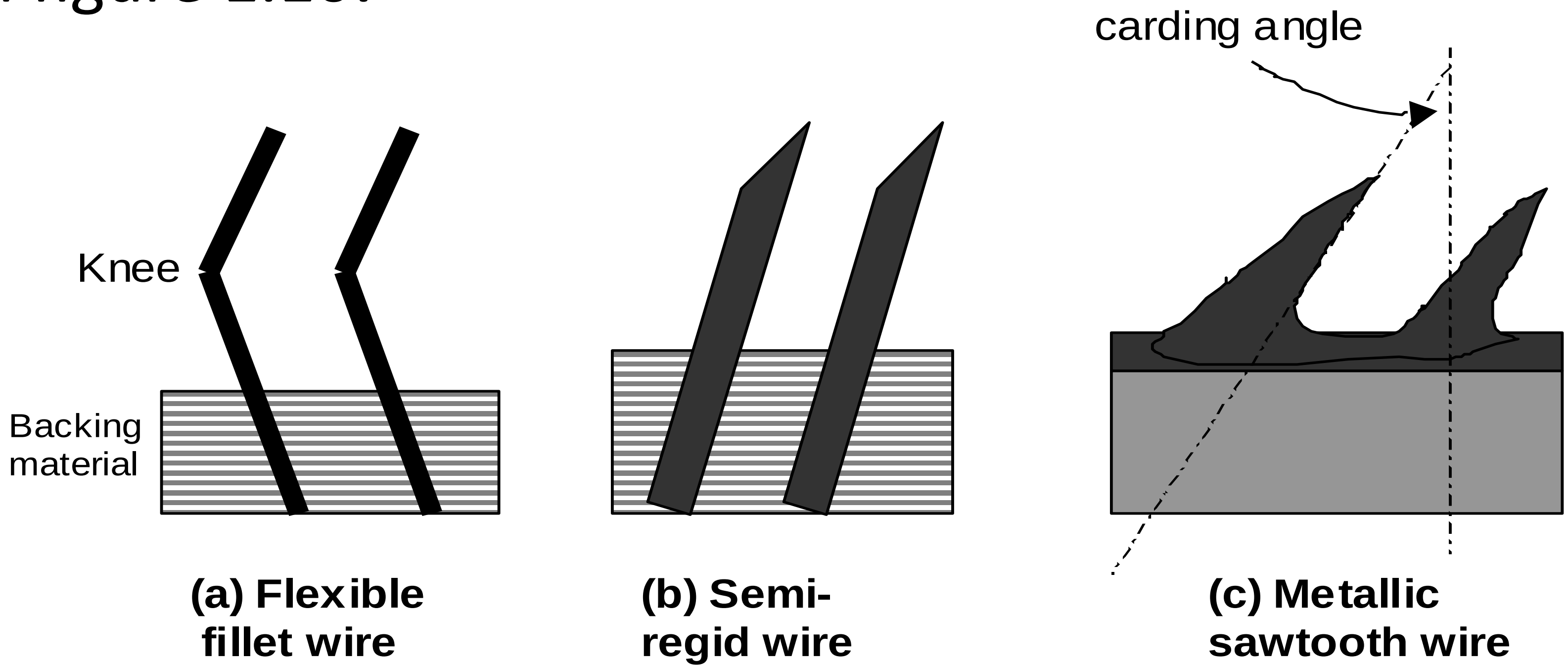


Figure 1.10 Different types of card clothing

The flexible fillet wire was developed to mimic the flexibility of natural teazles used in the past. This type of clothing is believed to minimise fibre damage during carding. The fillet wire is designed with a knee on each needle, so that when the needle bends back as force is applied during carding, the point of the needle does not project too far outwards. Otherwise the points on two adjacent surfaces will touch each other, causing damage to the needles. In other word, the knee is designed to prevent point-rise to avoid wire damage. The needles are embedded in the backing material. Dirt and short fibres tend to accumulate under the knees of flexible fillet wire. If not removed, carding efficiency will drop. Removing the dirts and short fibres from the card clothing is called card fettling.

The semi-rigid wire is often used on the flats of cotton cards. It is more rigid than the flexible fillet wire and has no knee. During carding, some short fibres and impurities will also accumulate in the semi-rigid wire. Long fibres have more contacts with the main cylinder clothing and will tend to move with the main cylinder. The short fibres and impurities removed from the clothing of flats are called flat strippings. Compared with flexible fillet wire, the semi-rigid wire has the advantage of not choking with fibres and correspondingly eliminating less flat strippings.

The metallic wire, also known as sawtooth wire, is a later development. It is less prone to damage and allows higher production rate. Modern high production cards are usually fitted with metallic fillet wire. The carding angle as indicated in figure 1.10 is the most important of the tooth. The higher the carding angle, the more aggressive the tooth is, and more fibres it will hold during carding. For this reason, the taker-in clothing usually has a very small carding angle, or even a negative carding angle so that fibres on the taker-in can be easily transferred to the cylinder. Similarly, the doffer clothing usually has a higher carding angle than the cylinder clothing to allow fibre transfer from cylinder to doffer.

- **Basic actions in carding**

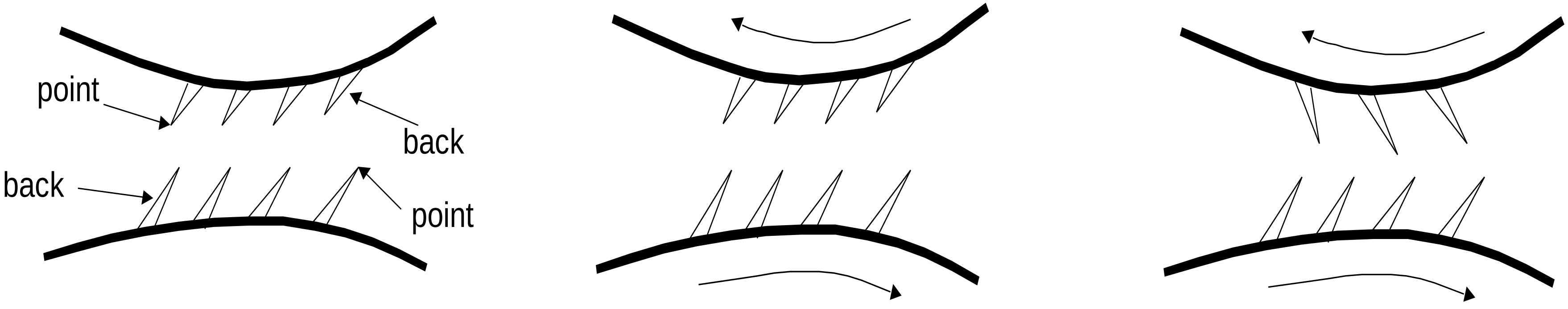
There are two basic actions in cotton carding: carding (or working) action and stripping action.

The tooth direction and relative surface speed decide which action occurs between two adjacent and clothed (or toothed) surfaces.

(a) Point-to-point carding

Each tooth has a point and a back, as indicated in figure 1.11a.

If the tip of the tooth on one surface points to the tip of the tooth on the other surface, a point-to-point carding (or working) action occurs (figure 1.11b).



(a) The Point and Back of a tooth

(b) Carding action (Point-to-point)

(c) Stripping action (Point-to-back)

Fig. 1.11: Carding and stripping actions

For instance, the teeth arrangements on flats and main cylinder, and on main cylinder and doffer (Figure 1.9) are typical point-to-point arrangements. Therefore carding action occurs between flats and main cylinder, and between main cylinder and doffer.

It is through the carding action that fibre opening occurs. Both surfaces contest for fibres and as a result, fibres are separated.

The level of fibre opening in carding can be represented by points-per-fibre. This is the ratio of the total infeed fibres per unit time over the number of working points available in the same time. As the card production rate increases, more fibres must pass through the card, this would reduce the number of points-per-fibre, hence the carding effect on the fibres. To maintain the carding effect, extra working points are added on modern cards.

(b) Point-to-back stripping

If the tip of the tooth on one surface points to the back of the tooth on the other surface, a stripping action occurs (figure 1.11). The point strips fibres off the back.

For instance, a stripping action occurs between the main cylinder and the taker-in. The teeth on the main cylinder point to the back of teeth on the taker-in, so the fibres on the taker-in are stripped by the teeth on the main cylinder.

It is through the stripping action that fibres are transferred from one surface to another during carding.

- **Quality of carded sliver**

The important quality considerations for the carded slivers are:

- Fibre length
- Number of neps
- Fibre alignment
- Sliver evenness

(1) Fibre length

As mentioned earlier, the intensive carding action causes considerable fibre damage and breakage, leading to reduction in fibre length and increase in short fibre content. Changes in mean fibre length before and after carding has also been used to estimate the level of fibre breakage in carding, using the formula below:

$$\%\,Fibrebreakage = \frac{Mean\ fibrelengthbefore\ carding - main\ fibrelengthafter\ carding}{ean\ fibrelengthafter\ carding}$$

(2) Number of neps

- Neps are highly entangled fibres. Usually a nep contains ten or more fibres. It is a very serious problem in the textile industry.
- The ease with which a fibre forms part of a nep is related to its bending rigidity. Immature cotton and fine fibres bend easily. They are prone to nep formation during carding. Many neps often persist into the final fabrics. Neps contain many immature cotton fibres, which have less cellulosic materials than mature fibres. During fabric dyeing, they do not take up as much dye as the rest of the fabric, causing a serious fabric fault known as “white specks”.
- Closer card settings between adjacent surfaces, sharper teeth, and higher doffer speed (reducing “recycling fibres”) can be used to reduce the number of neps in carding.

(3) Fibre alignment

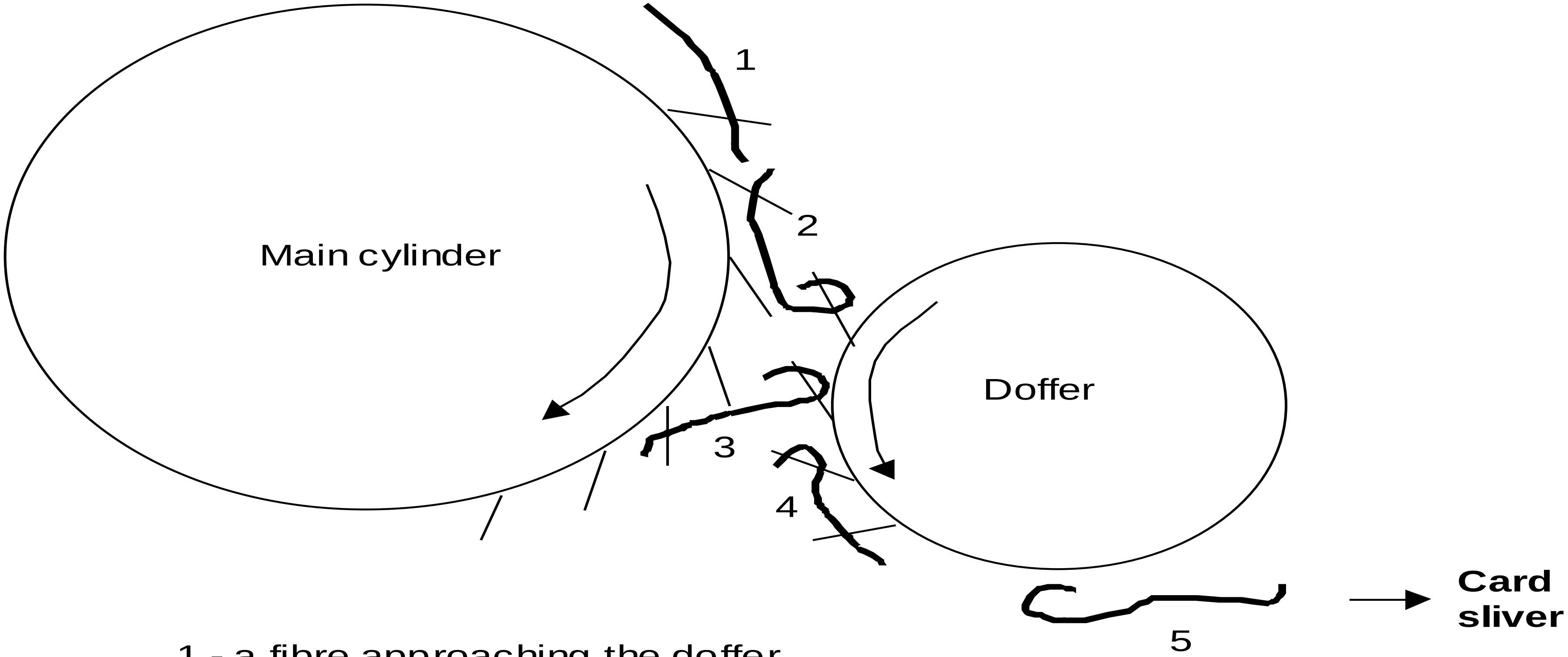
Ideally, fibres in a carded sliver should be straight and parallel. This is not quite the case. In a typical card sliver, the fibre configuration may be:

20% fibres - straight fibres
50% fibres - having trailing hooks (hooks at trailing fibre ends)
15% fibres -having leading hooks (hooks at leading fibre ends)
15% fibres -having hooks at both fibre ends

You may wonder how fibres get hooked up during carding.

Fibre hooks are created in carding by the doffer mainly. The doffer picks up fibres on the cylinder by allowing the fibre leading ends to hook around its teeth. The teeth on the fast-moving cylinder surface then comb and 'brush forward' the other ends of the fibres. Therefore, the fibres on the doffer surface have a majority of trailing hooks. This configuration persists to the carded sliver.

The generation of trailing hooks by the doffer is graphically illustrated below.



1 - a fibre approaching the doffer
2 - fibre leading end picked up by doffer
3 - fibre trailing end combed forward by cylinder
4 - trailing hook fibre formed on differ
5 - the trailing hook persists to carded sliver

Fig. 1.12: Formation of trailing hooks in carding

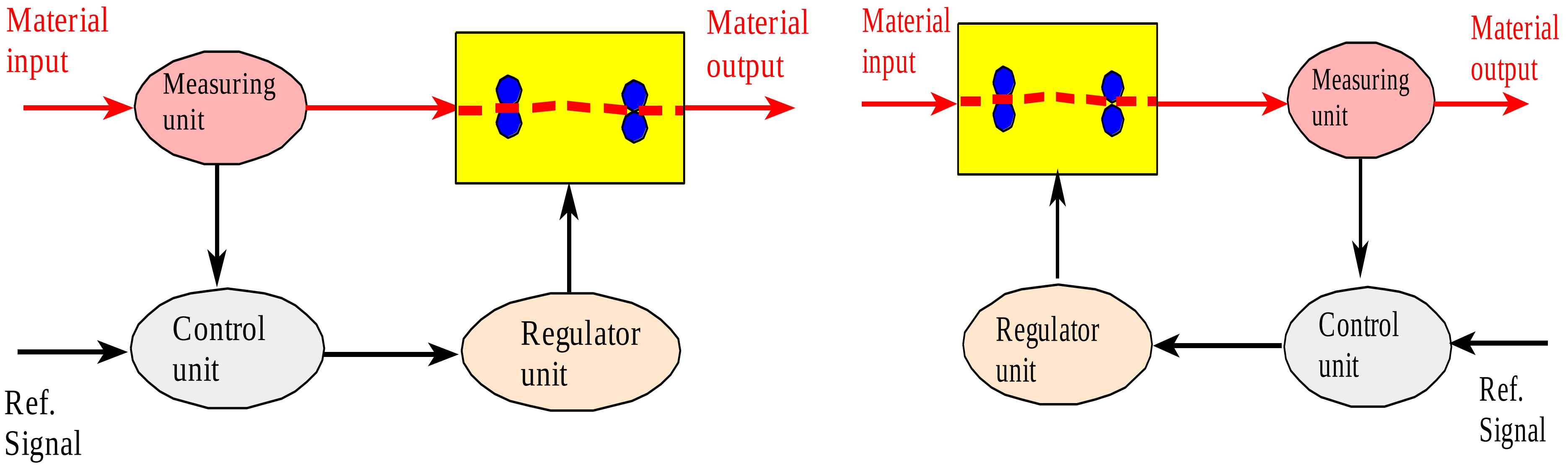
Further processing is therefore necessary to help straighten up these fibre hooks.

(4) Sliver evenness

It would be very difficult, if not impossible, to obtain an even yarn from irregular slivers.

Uniform feed to the card is essential for the uniformity of card sliver. Modern chute feed regulates the amount of fibres fed to the card to improve uniformity. In addition, some cards are fitted with an autoleveller or autolevelling system to ensure uniformity. An autoleveller is a system fitted to carding (and drawing) machines to automatically reduce the variation of the linear density of the output material. This is achieved by monitoring the linear density of the input or output material and, if necessary, changing the machine speed to compensate for any deviation from a pre-set value.

Two main types of autolevelling systems have been used on the carding machines: the open-loop (or feed forward) and closed-loop (feed backward) autolevelling systems. The principles of these two types are indicated in Figure 1.13.



Material input
Measuring unit
Material output
Control unit
Regulator unit
Ref. Signal

An open-loop (feed-forward) control

Material input
Measuring unit
Material output
Regulator unit
Control unit
Ref. Signal

A closed-loop control system

Fig. 1.13: Open-loop and closed-loop autolevelling systems

For the open-loop aultolevelling system, the linear density (or thickness) of the input material is measured by a measuring unit. The result is compared with a set value or the reference signal. If there is any deviation, the control unit will direct the regulator unit to change the process speed to maintain a regular output. In this case, the measured signal is fed forward from input to output, and this autolevelling system is also known as feed forward autolevelling system. This system is often used to correct short-term variations in linear density.

For the closed-loop autolevelling system, the linear density (or thickness) of the output material is monitored by a measuring unit. It is then compared with the set value or the reference signal. If the measured value deviates from the set value, the control unit will direct the regulator unit to change the process speed so that the deviation can be reduced. Since the measured signal is fed backwards from output to input, this system is also known as feedback autolevelling system. This system is suitable for correcting medium to long-term variations in linear density.

Figure 1.13a shows an open-loop autolevelling system on a cotton card . In this example, the thickness of the feed stock is measured at the feed roller. The thickness signal is then fed into a programmable controller which processes the signal and works out the correct draft required to adjust the weight of the material being processed, and commands a servo-motor to change the relevant roller speed to maintain a uniform output.

Figure 1.13a Open-loop autolevelling on a card (Lennox-Kerr 1983, p. 46)

A closed-loop autolevelling on a cotton card is shown in figure 1.13b. In this case, the thickness of the output sliver is monitored by a pneumatic measuring unit. The signal is fed back to the feed roller so that it can either slow down or speed up to change the draft.

Figure 1.13b Closed-loop autolevelling on a card (Klein 1987a, p54. Courtesy of Zellweger Uster).

Drawing

Converting bales of fibres to a thin strand of fibres or yarns requires enormous fibre attenuation. Put simply, attenuation (drafting) is to make input material longer and thinner. In this sense, carding can also be regarded as a fibre attenuation process. Drawing continues the fibre attenuation, it also performs several other functions.

- **Objectives**

The drawing process aims at achieving the following objectives:

- Attenuate the card slivers
- Reduce the fibre hooks and improve fibre alignment
- Blend and mix fibres
- Reduce the irregularity of card slivers by doubling

Drawing usually implies the actions of doubling and drafting. Doubling is the combing of several slivers and drafting is attenuation.

By now we already know that fibres in card slivers are by no means straight and parallel, and there are many hooked fibres, particularly trailing hooks, in the card slivers. Many of these hooks should be straightened as fibres slide past each other in the drawing process. Slivers from different cards vary evenness and other properties, and should be blended to reduce the irregularity. Cotton and synthetics are often blended in drawing in sliver form. Finally, when card slivers are combined (doubled), attenuation is necessary to reduce the thickness of the drawn sliver. Drawing plays a crucial role in the final quality of yarn, and a good understanding of the fundamentals of drawing is essential.

- **Basics of roller draftin**

  The basic elements of a roller drafting unit is shown in Figure 1.14.

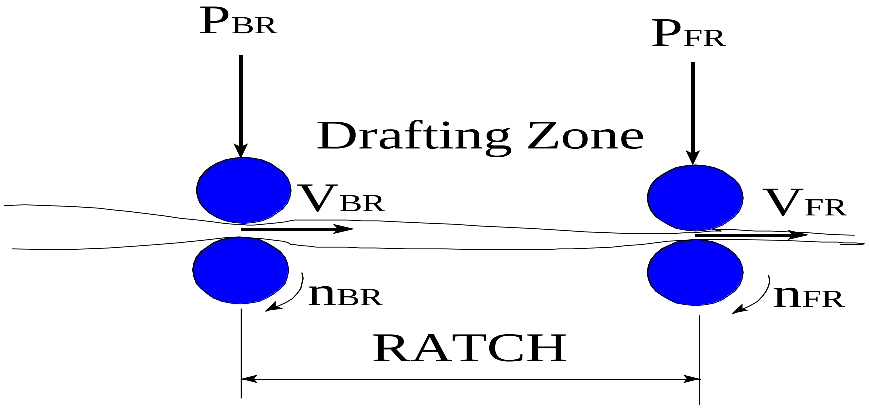


Figure 1.14 Basic elements of drafting

There are two sets of rollers, the front rollers (top and bottom) and the back rollers (top and bottom). The front rollers are also known as the delivery rollers while the back rollers the feed rollers. For drafting to occur, the front roller surface speed V_{FR} is faster than the back roller surface speed V_{BR}. The bottom rollers are the driving rollers, which drive the top rollers by frictional contacts. The top rollers are loaded by spring or dead weight to apply pressure to the fibre material running between the two sets of top and bottom rollers.

There are several important definitions with respect to roller drafting:

(a)Material Draft= $\frac{Input\,count\,(tex)}{Output\,count\,(tex)}$

(b)Mechanical Draft = $\frac{Output\,surface\,speed}{Input\,surface\,speed}$

(c)Drafting Zone = the region between the front and back rollers, where drafting occurs.

A drawframe usually has at least two drafting zones, and the total draft of the drawframe is not the addition, but multiplication, of the drafts in separate zones. For instance, if a drawframe has 3 drafting zones with drafts of D1, D2 and D3 respectively, then the total draft of the drawframe should be .

(d)Ratch = distance between the nip points of the front and back rollers.

(e)Doublings = number of slivers fed to the drafting system for one output sliver.

The material draft and mechanical draft are not always equal. The material draft is the real draft. The ratch is also known as the ratch length or ratch setting. It is set according to the length of the longest fibres in order to prevent these fibres from being stretched to break.

- **Perfect Roller Drafting**

Assuming all fibres are uniform in length and diameter, and straight and parellel to sliver axis. The position of each fibre in the sliver will be fully described by position of its fibre leading end (FLE) and its length. Existing textile processes can not arrange these fibres in such a perfect manner that a sliver would have the same number of fibres in its cross sections along its length (we call this sliver a perfect sliver). The best sliver that can be expected under optimum processing conditions is one in which the fibre leading ends (FLEs) are randomly distributed. A sliver with random FLEs distribution is called an ideal sliver.

For an ideal sliver to remain ideal after drafting, the random FLEs distribution should be maintained. This requires that the drafting should increase the distance between fibre leading ends by a factor exactly equal to the draft used, which can only be achieved through perfect roller drafting.

Achieving perfect roller drafting requires individual control and manipulation of single fibres during the drafting process, which is not possible with existing technology. Nevertheless, near-perfect roller drafting may be obtainable if the pressure distribution in the drafting zone is ideal.

- **Ideal Pressure Distribution**

The ideal pressure distribution indicated in Figure 1.15 has the following features:

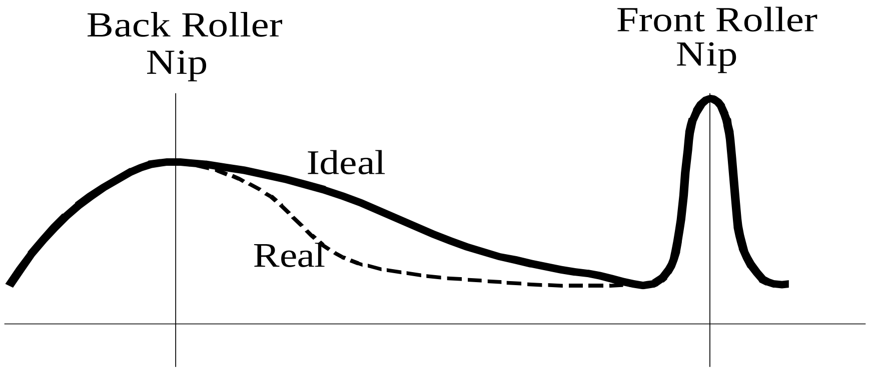


Figure 1.15 Ideal and real pressure distributions in simple roller drafting

(a) Back roller pressure is enlarged, in order to keep fibres move at back roller speed.

(b) Front roller pressure is more concentrated or narrow, so that fibres under the influence of the front roller pressure can change speed near the nip of the front rollers.

(c) Pressure from back rollers decreases gradually, so fibres are not held back while they get accelerated at the front roller nip.

With an ideal pressure distribution in the drafting zone, near-perfect roller drafting can be achieved.

The pressure distribution provided by a simple roller drafting system is indicated by the broken line in Figure 1.15. Such a pressure distribution does not facilitate a near perfect roller drafting and often some fibre control devices are needed in the drafting zone. Fibre control during drafting will be discussed later.

- **Real Drafting**

  In a real roller drafting situation, both the pressure distribution in the drafting zone and the slivers themselves are not as ideal as the ones mentioned above. Fibres in a real sliver are of different lengths and diameters. They are often not straight and parellel to sliver axis. Fibre leading ends may not follow a perfect random distribution. There are also grouping of fibres in the sliver due to fibre entanglements and frictional contacts. Besides, there may be variatiosn in roller speed and slippage between fibres and rollers etc. All these factors contribute to the fact that perfect roller drafting is not achieved in real drafting.

Because the ratch of a drafting zone is set according to the length of the longest fibres, many fibres are not gripped by either the front roller or the back roller nip for some part of their journey through the drafting zone. Figure 1.16 shows a simple roller drafting unit with three typical fibres of different lengths in the drafting zone. The three fibres a, b and c will behave differently during drafting.

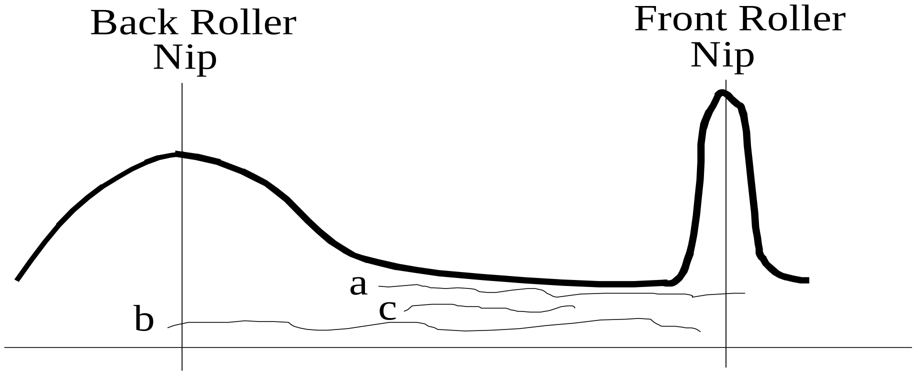


Figure 1.16 Movements of fibres in the drafting zone

Fibre a: The front rollers exsert more pressure on this fibre than the back rollers. It has been accelerated to the front roller speed and is a 'fast-moving' fibre, travelling at the speed of front rollers.

Fibre b: This fibre is under heavy control of the back rollers. It is a 'slow-moving' fibre.

Fibre c: This fibre is not under direct control of either roller nip. Fibres which are not gripped by either nip are known as 'floating fibres'. The movement of a floating fibre will depend on its surrounding fibres. If it is surrounded by some slow moving fibres and some fast moving fibres, it may be accelerated before its leading end reaches the front roller nip if the sum of the frictional forces between it and the fast moving fibres is greater than the sum of the frictional forces between it and the slow moving fibres. A floating fibre like fibre c may also accelerate to immediate velocities depending on the ratio of the frictional forces. Floating fibres are obviously short fibres. Another feature of this floating fibre is that once it gets accelerated, it moves faster than other longer ones because there is less restraining force on its short training end.

The following observations can be made from this simplified description of fibre movements.

(1)Speed change zone

Not all fibres change their speeds, or get accelerated at the front roller nip as required by perfect roller drafting, because fibre lengths are different and fibres at the edges of the drafting zone are unpredictable (edge fibres can not be controlled effectively). There is a speed change zone near the front roller nip. This speed change zone will be more localised towards the front roller nip if fibre length is more uniform.

(2)Drafting wave due to floating fibres

Since the movement of a floating fibre depends on its contacts with neighbouring fibres. Some floating fibres may be pulled forward out of turn by the neighbouring fibres that have already been accelerated. Floating fibres accelerating out of turn can cause adjacent fibres to also accelerate, creating a thick place. The thick place is then drawn forward by the front roller nip, leaving a thin place behind. This process repeats to produce alternatively thick and thin places in the drafted fibre assembly. This is a practically periodic irregularity, and is widely known as a 'drafting wave', because it is caused by floating fibres during drafting. The wavelength of a drafting wave is about 2.5 times the mean fibre length.

(3)Drafting wave due to sliver elasticity

Due to crimp and poor orientation and entanglement of fibres, slivers are elastic over small strains. They can stretch under the drafting force. As the fast moving fibres are withdrawn from the bulk of the sliver, their frictional contacts with the sliver create a withdrawal force, which then extends the sliver. This extension will cause the fibre leading ends to reach the front roller nip and accelerate ahead of their turn, and so produce a thick place. A thick place means more fast moving fibres and higher withdrawal forces and more extension, causing more fibres to accelerate ahead of their turn until the sliver reaches the limit of its extension. At this level of extension, the number of fibres reaching the front roller nip settles back down to the normal level, and so the number of fast moving fibres (& withdrawal force) decreases. The reduction in withdrawal force causes the sliver to retract, so fibres reach the front roller nip later than expected, producing a thin place. Again, this process repeats and drafting wave is produced. The wave length of this drafting wave is also about 2.5 times the mean fibre length.

(4)Periodic mass variations due to mechanical faults

If there are mechanical faults in the drafting system, such as eccentric drafting rollers, periodic mass variation will result in the drafted material. This phenomenon has been discussed in the module on yarn evenness.

In summary, real drafting may deviate from perfect roller drafting because of either material related or machine related factors. In practice, fibre control during drafting is necessary to reduce this deviation.

- **Fibre Control in Roller Drafting**

The main aim of fibre control is to keep the floating fibres at the speed of back rollers until they reach the front roller nip (i.e. to prevent fibres being accelerated out of turn), while still allowing long fibres to be drafted.

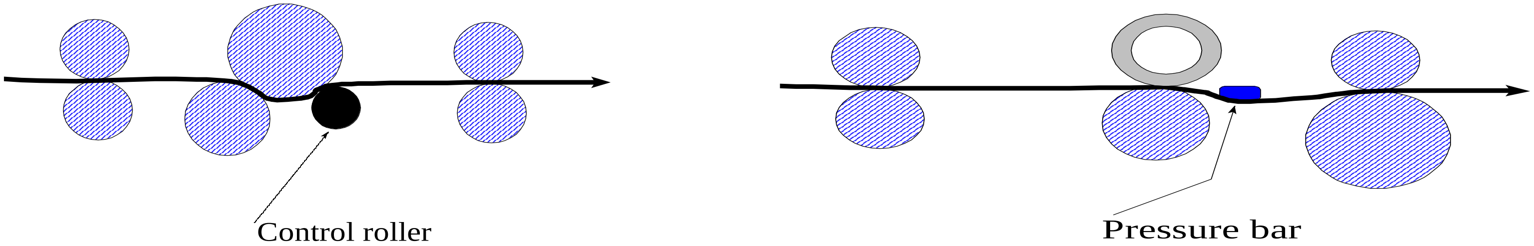


Figure 1.17 Examples of fibre control for the Short Staple Drawframes

Different yarn manufacture systems, and different process in the same system, often apply different control device in drafting. Two examples of fibre control in short staple drawing machines (drawframes) are shown in Figure 1.17. The control roller and pressure bar force the fibre assembly (in the drafting zone) to take a curved path, thus increasing the pressure on fibres at the control roller or pressure bar. The increased pressure helps to control fibre movement during drafting.

- **Doubling in Drawing**

As mentioned in the beginning, drawing often implies the actions of doubling and drafting. We have already discussed drafting at length. Doubling simply means combining several slivers together as the input to a drawframe. According to the law of doubling discussed in the module on yarn evenness, if n slivers are doubled together, the CV of the doubled material will be reduced by a factor of or $^1/_{\sqrt{n}}$

$$CV_{after\ doubling} = \frac{\overline{\mathrm{CV}}_{\mathrm{before\,doubling}}}{\sqrt{\mathrm{n}}}$$

where $\overline{CV}_{before\,doubling}$ is the average CV of the individual slivers before doubling

Usually 8 slivers are doubled up to give one output sliver, as indicated in Figure 1.18. The linear density of the output sliver is determined by the amount of total draft applied in the draft zone.

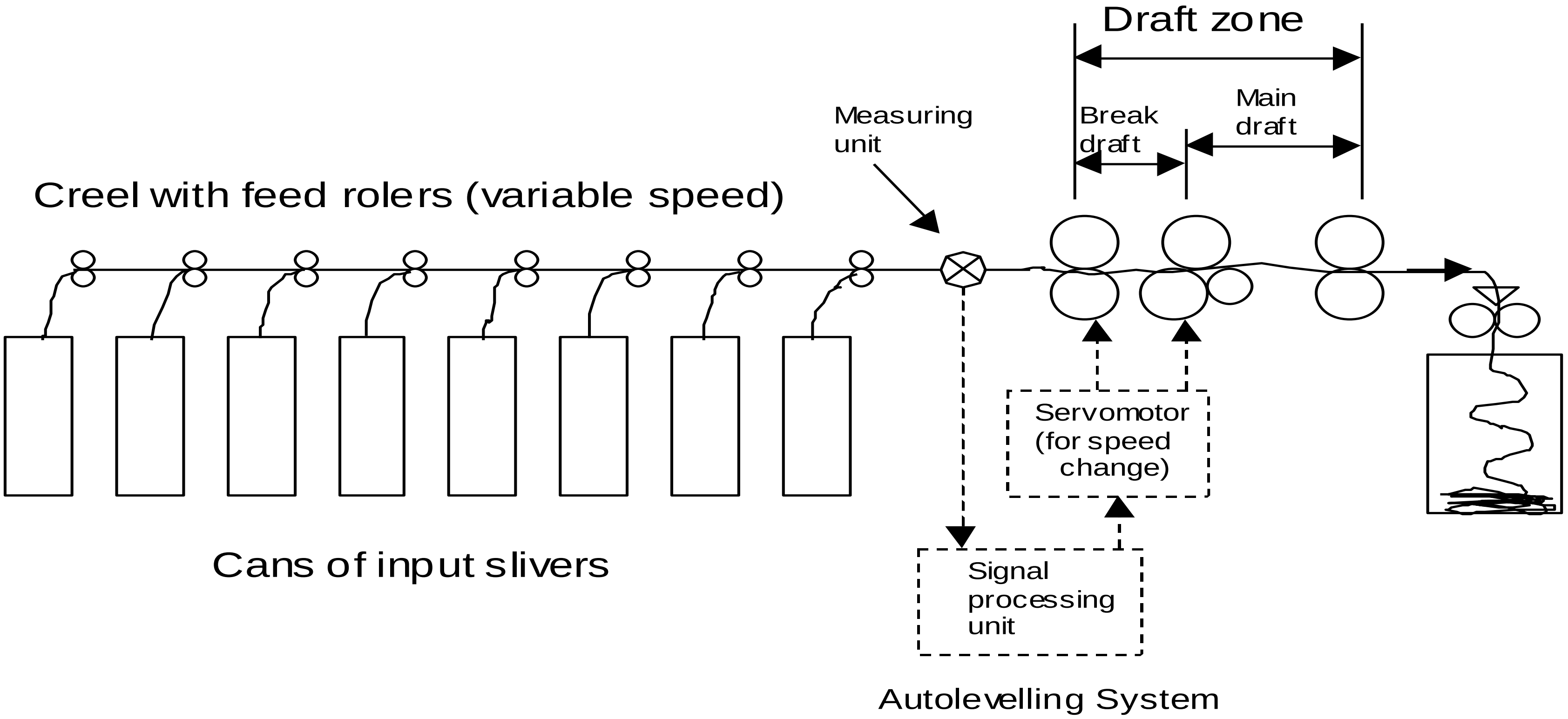


Figure 1.18 A drawframe with 8 doublings and an autolevelling unit

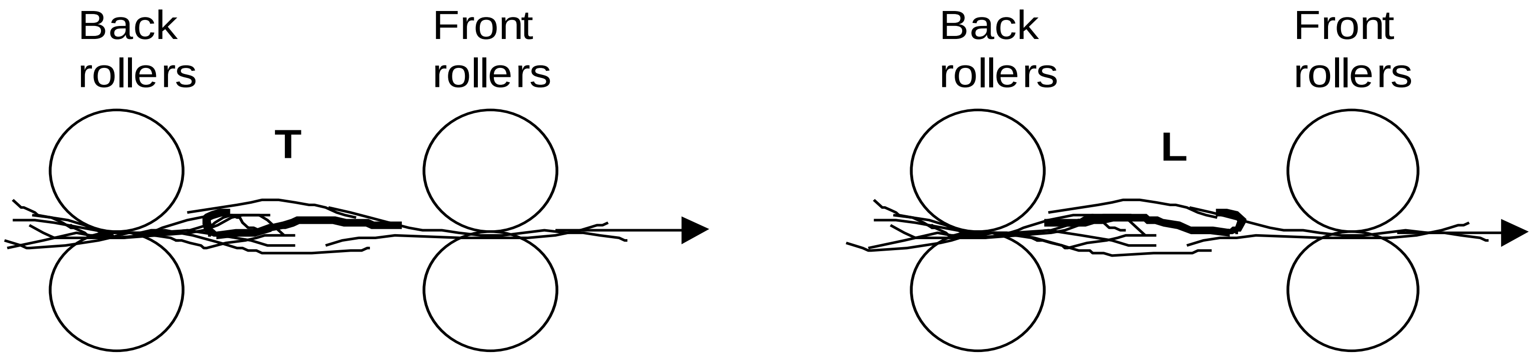
- **Autolevelling in Drawing**

Fibre control and doubling are necessary in drawing to improve the quality, particularly evenness, of drawn slivers. As in carding, autolevelling is often used in drawing to further improve the evenness of drawn materials. The principle of autolevelling has been discussed in the carding section. An example of autolevelling in drawing is shown in figure 1.18. This is an open-loop or feed forward autolevelling system. The input material is measured for linear density or thickness by a measuring unit, the signal is processed and compared with set value by the signal processing unit. If deviation exists, then the servomotor is instructed to change the speed of the drafting rollers to adjust the draft in other to reduce the irregularity of the output material.

- **Fibre Straightening in Drawing**

We already know that most fibres in card slivers are hooked fibres, and one of the key objectives of drawing is to straighten out these hooked fibres.

Consider a trailing hook (T) and a leading hook (L) in drawing as shown in Figure 1.19.



Trailing hook in the drafting zone (straightens out easily)

Leading hook in the drafting zone (does not straighten out easily)

Figure 1.19 Fibre straightening during drafting

For the trailing hook, it will travel initially at the speed of the back drafting rollers. Soon its leading end, embedded in ‘fast-moving’ fibres under the influence of the front drafting rollers, will travel with the ‘fast-moving’ fibres at the front roller speed. Since the hooked end of the fibre is still embedded in a relatively thick body of ‘slow-moving’ fibres controlled by the back rollers, the difference in speed between the leading end and trailing (hooked) end will straighten out the hook. For the fibre with leading hook (L), the hook can get caught easily by the ‘fast moving’ fibres and travel at the front roller speed, while the unhooked trailing end offers little resistance to its acceleration. As a result, the leading hook (L) is likely to persist into the output material. From this brief discussion, it is clear that one passage through a drawframe only effectively removes trailing hooks.

In a card sliver, the majority of fibre hooks are trailing hooks. But as the card sliver is deposited into a can and gets taken out to feed a drawframe, it follows a ‘first-in-last-out’ principle and a reversal of hook direction occurs. This is known as natural reversal of fibre direction. Because of this natural reversal, most fibres (in the card slivers) entering the first drawframe have leading hooks, which do not get effectively straightened out as we have just discussed. In addition, a short staple combing machine (the comber) straightens out leading hooks effectively (which is different from a worsted comb for long staple fibres), and trailing hooks must be presented to a ring spinning machine (the drafting in ring spinning does not straighten out leading hooks).

For these reasons, there must be an even number of passages between the short staple carding and combing machines, and an odd number between the short staple carding and ring spinning machines. You can see this arrangement from Figure 1.1.

Figure 1.1 indicates that after two drawing passages, the sliver can go directly to rotor spinning to produce a carded rotor spun yarn. However, if a high quality ring spun cotton yarn is required, the sliver should go through a combing stage, followed by further drawing, roving and finally the ring spinning process. Combing is discussed next.

Combing

- **Introduction**

Combing is a key process that makes the difference between an ordinary yarn and a quality yarn. It enables the ultimate yarn to be smoother, finer, stronger, and more uniform than otherwise would be possible, at a cost of course.

The basic objectives of combing are:

(a) Removal of a pre-determined amount of short fibres
(b) Removal of neps and impurities
(c) Straightening of the retained long fibres

The continuous assembly of long and parallel fibres delivered by the combing process is called a comb sliver. Just as long and well-aligned fibre polymers (molecules) make strong fibres, long and straight fibres in the comb sliver will make strong and smooth yarns.

The materials rejected in the combing process is called noil. Noil contains short fibres, neps and impurities. The amount of noil produced may be expressed as either percentage noil or tear ratio:

$$Percentage\, noil = \frac{weight\, of\, noil}{weight\, of\, (noil + comb\, sliver)} \times 100$$

$$Tear\ ratio = \frac{weight\, of\, comb\, sliver}{weight\, of\, noil} : 1$$

The relationship between the two expressions is given below:

$$Percentage\, noil = \frac{100}{(tear + 1)} \qquad or \qquad Tear = \left(\frac{100}{percentage\, noil}\right) - 1$$

For example, a 10% noil is equivalent to a tear ratio of 9 : 1, and a 16% noil is equivalent to a tear ratio of 5.25 : 1.

The amount of noil produced is of significant importance. A higher noil means longer fibres in the comb sliver, but less comb sliver will be produced.

Yarns made from the combed sliver are called combed yarns. Without combing, a carded yarn would be produced. Combed yarns, consisting of longer and more parallel fibres, are of better quality and command a higher price than carded yarns or yarns produced without the combing stage. A brief comparison of combed and carded cotton yarns is given in Table 1.2 below. `

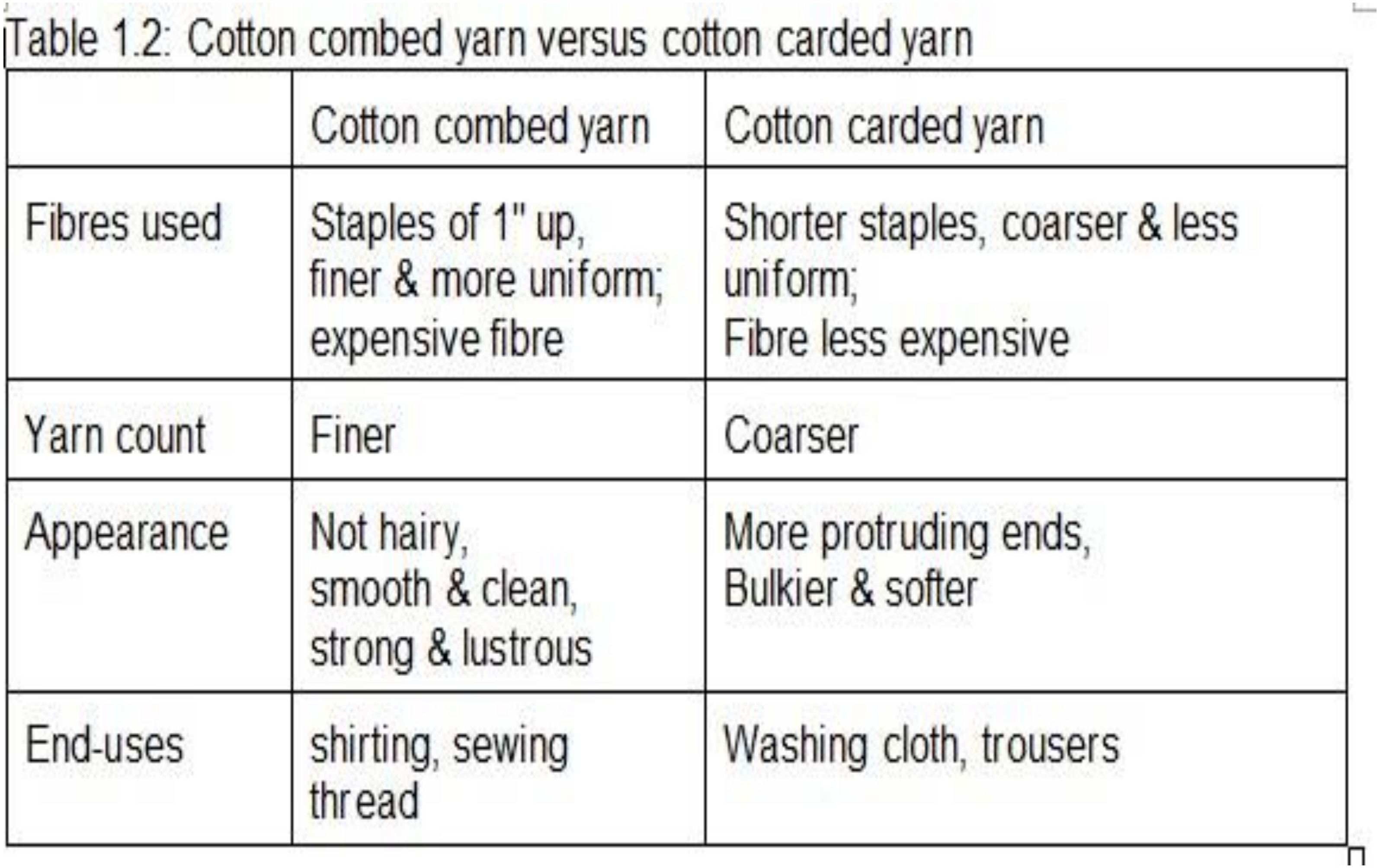


Table 1.2: Cotton combed yarn versus cotton carded yarn

	Cotton combed yarn	Cotton carded yarn
Fibres used	Staples of 1" up, finer & more uniform; expensive fibre	Shorter staples, coarser & less uniform; Fibre less expensive
Yarn count	Finer	Coarser
Appearance	Not hairy, smooth & clean, strong & lustrous	More protruding ends, Bulkier & softer
End-uses	shirting, sewing thread	Washing cloth, trousers

- **The comb**

A combing machine is usually referred to as a comber, or simply a comb. The short-staple spinning mill uses only the rectilinear comb with swinging nippers and stationary detaching rollers, as originally conceived in 1845 by J. Heilman in Alsace and further developed in 1902 by the Englishman Nasmith and in 1948 by the Whitin company.

The most common machine layouts used in practice comprise single-sided machines with eight heads. Double-sided machines with six-plus-six head are also manufactured by the Platt Saco Lowell company.

A typical comb head is sketched in Figure 1.20.

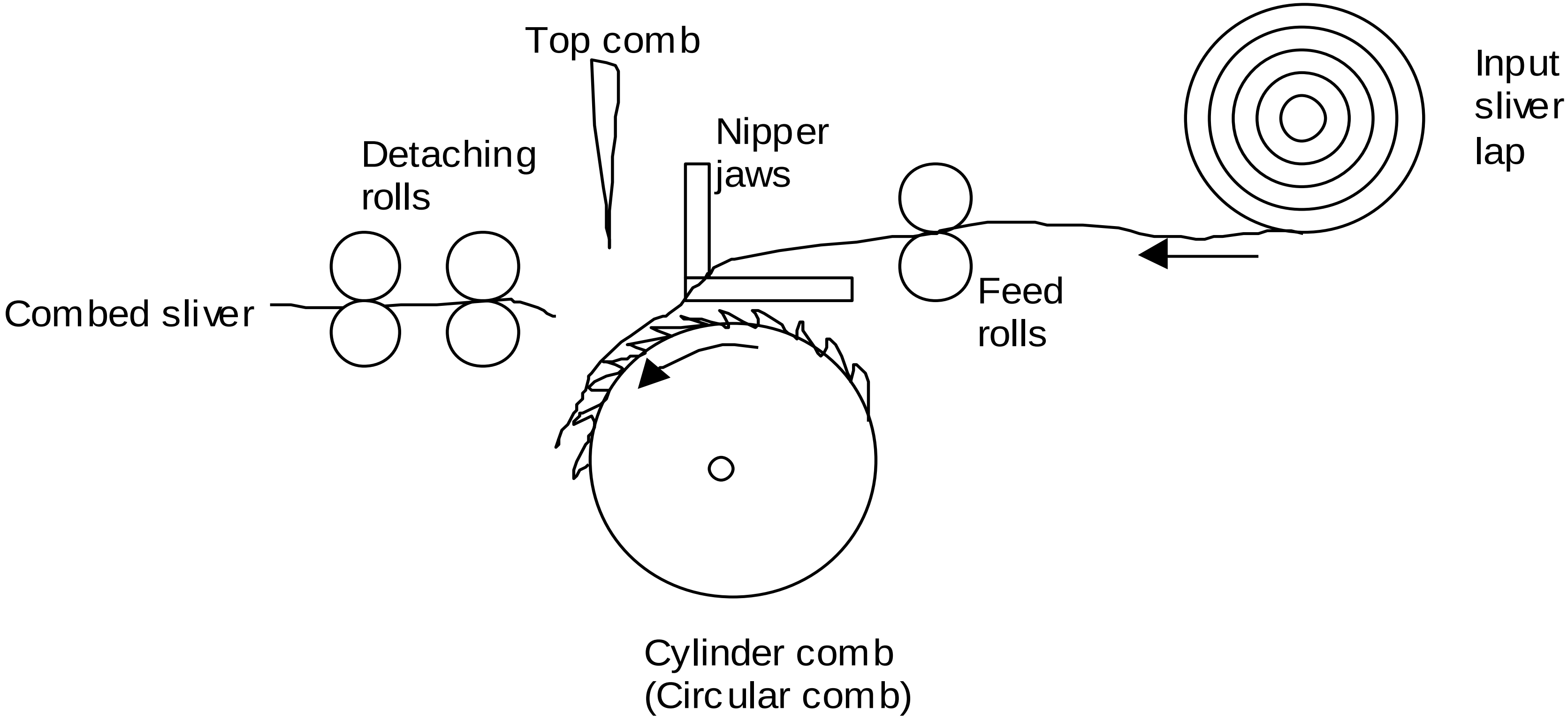


Figure 1.20 Sketch of a rectilinear cotton comb

The sliver lap, or the thick sheet of fibres formed on a sliver lapper before combing, is fed to the comb in an intermittent fashion. In each operating cycle, the lap is advanced a short distance (4 to 6.5 mm) and then gripped (by the nippers) so that a fringe of fibres is presented to the toothed section of a cylinder comb. The fibre fringe is then combed by the teeth on the cylinder comb and in the process, short fibres, neps and impurities are removed from the fringe. The short fibres, neps and impurities are collectively called noils. When the un-toothed portion of the comber roll comes into contact with the fringe, the nippers open and swing towards the detaching rollers to allow the fringe to be drawn off by the detaching (or draw-off) rolls.

The closest distance between the nipping points of the nippers and the detaching rollers is called by several names – gauge setting, detachment setting, noil setting. This setting is the most important setting on a comb. It has the largest impact on the percentage noil and the mean fibre length of the comb sliver. During the drawing off process, the fibre fringe is pressed into the needles of the top comb, so that the portion of the fringe not combed by the cylinder comb can now be combed by the top comb. The neps and impurities will not be able to pass through the closely pinned top comb and are removed by the cylinder comb in the next combing cycle.

The detaching rolls bring the combed fringe to the tail end of the previously combed material to make a joint or piecing. The combed fibres, from many combing heads, are then brought together and consolidated into a sliver and coiled into a sliver can.

The comb operates intermittently in cycles. Its speed is described in terms of cycles per minute or nips per minute. Modern cotton combs run in excess of 350 nips/minute

- **Sequence of operations**

The sequence of operations of a cotton comb is described below

(a) The feed rollers S move the sheet W 4 – 6.5 mm forward, while the nippers ZO/ZU are held open (feed).

(b) The upper nipper plate ZO is lowered onto the cushion plate ZU so that the fibres are clamped between them (nipping).

(c) The combing segment (K), mounted on rotating cylinder (Z), sweeps its needles or saw-teeth through the fibre fringe (B) and carries away anything not held by the nippers (rotary combing).

(d) The nippers open again and move towards the detaching rollers A (nippers forward).

Figure 1.21 Sequence of operations of a cotton comb (Klein, 1987b, p2-4) (e)Meanwhile, the detaching rollers A have returned part of the previously drawn off stock (web V) by means of a reverse rotation, so that the web protrudes from the back of the detaching device (web return).

(f)In the course of the forward movement of the nippers, the projecting fibre fringe B is placed upon the returned web V (piecing).

(g)The detaching rollers begin to rotate in the forward direction again and draw the clamped fibres out of the sheet W held fast by the feed rollers (detaching).

(h)Before the start of the detaching operation, the top comb F has thrust its single row of needles into the fibre fringe. As the fibres are pulled through the needles of the top comb during detaching, the trailing part of the fringe is combed, thus making up for the inability of the cylinder comb to reach this part of the fringe (combing by the top comb).

(i)As the nipper assembly is retracted, the nippers open for the next feeding step. The top comb is withdrawn. A new combing cycle begins.

- **Fibre selection in combing**

The theory of combing deals with the key issue of fibre selection in the combing process, i.e. what goes into the noil and what goes into the comb sliver. The percentage noil is largely a function of the detachment setting and the feed distance per combing cycle. It is worth pointing out here that there are two types of feeding arrangements – concurrent feed and counter-feed. With concurrent feed, the fibre sheet is fed forward into the nippers while the nippers are swinging towards the detaching rollers. With counter-feed, the fibre sheet is fed forward during the return of the nippers. The type of feeding also affects the percentage noil in combing.

According to Charles Gegauff's noil theory, the percentage noil (N%) are related to the detachment setting (D), feed distance (F), and the longest fibre length (L), according to the formula below:

$$N\% = \left(\frac{D + {}^{F}\!/_{2}}{L} \right)^{2} \times 100 \qquad (For\, counter\, feed)$$

$$N\% = \left(\frac{D - {}^{F}\!/_{2}}{L} \right)^{2} \times 100 \qquad (For\, cocurrent\, feed)$$

It should be noted that these formulas are used to reflect the relationship between percentage noil and important comb settings, not to calculate the actual percentage noils. The implication of this relationship on the quality of comb sliver is discussed in the following section.

- **Quality issues in combing**

The theory of combing or noil theory discussed in the previous section provides a good starting point on the quality issues in combing. Research at Rieter has shown that the percentage noil has a major impact on the important quality attributes of the resultant yarns, as depicted in Figure 1.22.

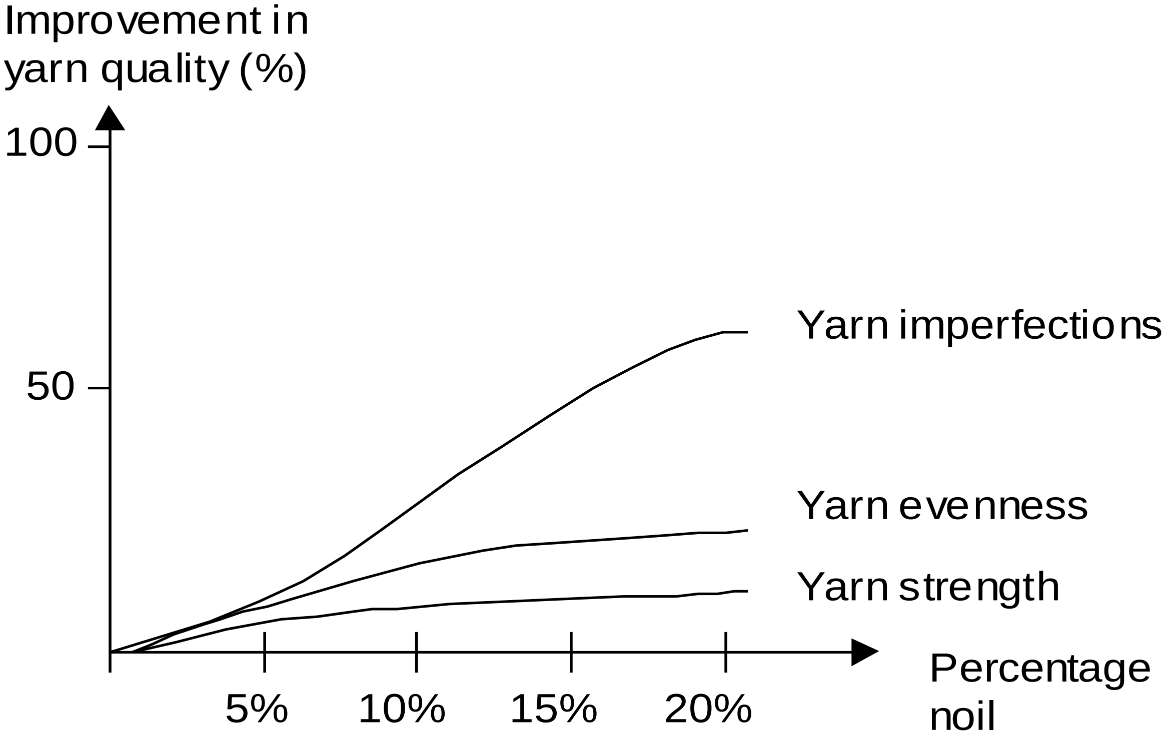


Figure 1.22 The effect of percentage noil on yarn quality attributes

In a normal combing process for cotton, a percentage noil between 10 to 20% is expected. Combing with a noil percentage below 10% is often referred to as upgrading combing, while combing with a noil percentage about 20% is known as super combing. Super combing is only used when superfine combed yarns are to be produced.

Now that we know the importance of percentage noil, what are the major factors that affect percentage noil in combing then? We will need to refer to the noil theory to answer this question.

(1)The detachment setting (D)

As mentioned before, this setting is the closest distance between the bite of the nippers and the nip line of the detaching rollers. According to the noil theory, the percentage noil increases as the detachment setting increases. At larger detachment setting, more fibres are removed into the noil and the average fibre length in the comb sliver is longer. Because of the increased fibre loss with increase in detachment setting, the cost of production will be higher. In practice, spinners need to find the optimum detachment setting based on a balance of quality and cost. The detachment setting on a cotton comb normally lies in the range 15 to 25 mm.

(2)The feed

According to the noil theory, both the type of feed and the feed distance affect the percentage noil. For the same feed distance, counter-feed results in higher noil percentage than concurrent feed. In other words, there are more short fibres in the comb sliver with concurrent feed than with counter-feed. In upgrading combing where the quality requirement is low and production rate needs to be high, concurrent feed is often used. On the other hand, if the quality requirement is very rigorous, counter-feed should be used. Some modern combs allow selection of the feed type according to needs.

The feed distance affects the noil, the quality and the production rate of combing. According to the noil theory, noil increases with feed distance for counter-feed, and decreases with feed distance for concurrent feed. Increase in the feed distance will increase production rate, because more fibres go into the comb sliver at a larger feed distance. But the cleanliness of the combed web, i.e. its freedom from impurities and neps, will deteriorate at a higher feed distance. Therefore, a lower feed distance needs to be used for higher quality requirements.

(3)Effect of fibre hooks

The cotton comb deals with relatively short fibres, compared with worsted comb. The hooks on short fibres are small. As a result, leading hooks can be removed easily by the cylinder comb, with little damage or breakage to the hooked fibres. An exception is when that both limbs of a leading fibre hook are held in the nippers while the protruding loop is still long enough to be engaged by the teeth on the cylinder comb. This event is much rarer in short staple combing than in long staple combing.

Trailing hooks can cause serious problems in short staple combing. Some trailing hooks may persist into the comb sliver or cause fibre breakage during detaching, particularly if concurrent feed is used. Consider a fibre with a trailing hook just lying in the bite of the nippers. With concurrent feed, the trailing hook will be pushed forward out of the nippers as the nippers swing towards the detaching rollers. The subsequent detaching action may drag this fibre (and its trailing hook) into the comb sliver, particularly if this fibre is near the bottom of the fibre sheet where the top comb has not yet penetrated. If this fibre's trailing hook is engaged by the top comb, fibre breakage is likely to occur because of the high friction between the hook and the top comb needle. With the counter-feed, no feeding occurs during the forward movement of the nippers.

During detaching, the fibre fringe gets pressed into the top comb in front of the nippers, and the trailing hook in the fibre concerned is likely to be combed by the top comb. In such case, the fibre could be combed straight unharmed and dragged into the comb sliver, or the fibre may be broken because of the friction between the fibre and the needles of the top comb. The fibre breakage will generate two short fibres, one proceeding to the comb sliver, and the other blocked by the top comb but removed as noil in the next combing cycle. This has two major undesirable consequences – short fibres in the comb sliver and increased combing waste.

The trailing hook, or other forms of fibre disorientation, may also carry its neighbouring short fibres forward to be detached by the detaching rollers, again increasing the number of short fibres in the comb sliver. Large trailing hooks will also reduce the effective length of even a relatively long fibre. The comb is likely to treat this fibre just like an ordinary short fibre and remove it into the noil. In other words, trailing hooks (or other forms of fibre disorientation) can also increase the number of long fibres in the noil, which of course is undesirable.

From this discussion, it is clear that good fibre alignment in the feed lap is essential for quality combing. Trailing hooks are particularly troublesome. This requires good lap preparation before combing. It also requires that an even (i.e. two) number of machines between the card and the comb, as indicated in Figure 1.1. This ensures leading hooks mainly are fed into the cotton comb.

(4) Comb overlap effect in piecing

At the end of each combing cycle, a small tuft of combed fibres is detached. This tuft is then partially overlapped on the previously detached tufts, like shingles on a roof or roofing tiles. Such pieced structure, or the comb overlap effect, is an inherent source of faults in the operation of rectilinear combs. Because of this, the combed sliver exhibits periodic mass variations along its length, which can be revealed using the spectrogram.

The combing process is normally followed by one or two passages of drawing before spinning. The drawing subsequent to combing will reduce the comb overlap effect. If a combed ring spun yarn is to be produced, a roving process is needed before the ring spinning process.

Roving

- **Introduction**

A roving is a fine strand (slubbing) intended to be fed into the ring spinning machines (ring frames) for making yarns. Rotor spinning machine and other new spinning systems use slivers as feed materials. But conventional ring frames still use rovings as the feed material. A roving is much thinner than a sliver, but thicker than a yarn.

The main objective of the roving machine is to further attenuate the drawn sliver (to make it longer and thinner) and get it ready for spinning.

The drawframe has already produced a sliver that is clean, and consists of more or less parallel fibres. Such a sliver satisfies the essential requirements for yarn production. The question is why is there a need for the roving process and why can’t we feed slivers to conventional ring frames? There are two major reasons for this need. First, a very high draft, in the order of 300 to 500, is required to bring the thickness of a sliver into the thickness of a yarn. Conventional ring frames can not cope with such a high draft. Second, the drawframe slivers are deposited in bulky sliver cans, which are difficult to transport and present to the ring frames as feed material. The much smaller roving packages are better suited for the purpose.

- **Roving frame**

The commonly used roving machine for cotton is a flyer frame (or speed frame) as shown in Figure 1.23.

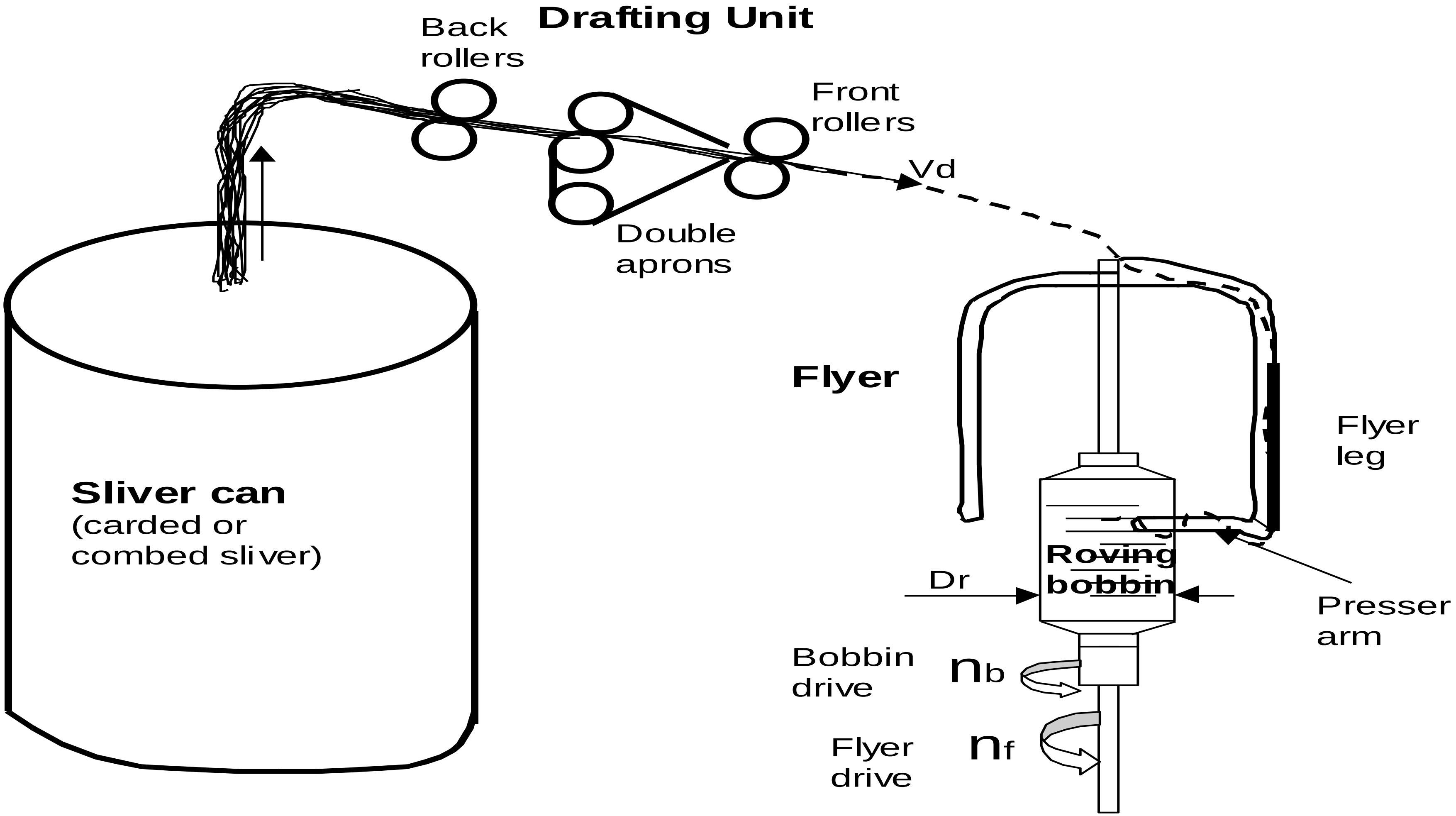


Figure 1.23 Diagram of a roving frame

There are three basic steps in the operation of the roving frame – drafting, twisting, and winding. These basic steps are exactly the same as the basic steps required in spinning. Consequently, an understanding of the roving process will help us understand the spinning process to be discussed in the next module.

The input to this roving frame is a drawn sliver (either carded or combed) from the last drawing process. The sliver is drafted by a roller drafting unit. Between the front and back rollers (the drafting zone), the fibres pass between the double aprons, which control the fibre movement during drafting. The front nose of the double aprons is set close to the front roller nip for good drafting performance. You may recall the concept of perfect roller drafting, which requires that fibres in the drafting zone travel at the speed of back rollers until the fibre leading ends reach the front roller nip. The double aprons travel at about the same speed as the back rollers, and they control the fibres until they reach the front roller nip.

A small amount of twist (30 to 65 turns per meter) is inserted into the drafted fibre strand via the rotation of the flyer. The bobbin (on a spindle) is driven at a speed different to that of the flyer. The different in bobbin and flyer speeds allows the slightly twisted fibre strand or roving to be wound on the bobbin. If the rotations of the bobbin and the flyer are synchronised, the roving will not be wound up onto the bobbin. The flyer arm through which the roving passes helps to support the relatively weak roving due to its low twist level.

In addition, a presser arm is attached to the lower end of the hollow flyer leg (through which the roving runs). This presser arm guides the roving from the exit of the flyer leg to the roving package. The roving is wrapped two or three times around the presser arm. The friction between the roving and the presser arm will increase the roving tension at the winding on point. This will give a compact roving package. A compact package has more roving and is more stable as well.

On the roving bobbin, each coil of roving material is arranged very closely and almost parallel to one another (parallel wind so that as much material as possible is taken up in the package. For this purpose, the bobbin rail (not shown in the diagram) with the package on it moves up and down steadily. The build-up of roving package leads to an increase in the wound length of roving per coil. The speed of the bobbin rail movement is reduced by a small amount after each completed layer. With the increase in package diameter (Dr), the bobbin rotation rate is also changed to maintain a constant difference between the surface speeds of the package and the flyer. This speed difference is the winding on speed and should be the same as the speed at which the fibre strand is delivered by the front drafting rollers.

The working principle of the flyer roving frame can be summarised as below:

- roller drafting, delivers fibre strand at a constant speed V_d
- flyer rotate at nf (constant) to twist the strand

$$Twist\ level = \frac{n_f}{V_d}$$

- bobbin rotates at nb (different to nf) to wind on the roving

  - either bobbin lead or flyer lead, as long as there is a difference in rotational speed

  - winding on speed $V_W = \pi Dr(n_f - n_b)$

  (Dr= roving diameter on bobbin)

- Dr varies as the roving package builds up, change nb to match VW with Vd

- fibre strand is supported by a flyer arm (no ballooning, best for thick weak strand)

  - flyer speed is limited by the mechanical design.

- **Quality issues in roving**

Since ring spun yarns are produced directly from rovings, the quality of the roving is very important. The roving process is essentially a drafting process (not a drawing process because there is no doubling). In fibre drafting, fibre control is important. Good condition of the double aprons, the right ratch setting (distance between the front and back drafting rollers) are important in ensuing good fibre control.

Rovings should be routinely sampled and tested for evenness. Particular attention should be paid to the spectrogram to see if any drafting wave or periodic mass variation exists in the rovings.

The small amount of twist inserted in the roving is necessary to ensure trouble-free transport of the roving package, smooth unwinding of the roving at the ring frame, and to prevent accidental drafting of the roving during roving winding. This twist should be as small as practically possible for two reasons. First, if the flyer rotation speed is fixed, a higher twist level means lower delivery speed or lower production rate. Second, high twist in the roving may cause problem in drafting of the roving at the ring frame, because fibres may not be able to slide past one another freely. The machine manufacturers will recommend the right level of twist for different fibre materials used.

Review questions

1.The key processing stages for cotton include

- opening and blending
- carding
- drawing
- combing

Describe the objectives and principle of each of these processes, using sketches if necessary and use about 200 words for each process.

2.Four bales of cotton, of 500 pounds each, are to be mixed together for the blow-room process. If the cotton fineness in these bales is, 3.8, 4.1, 4.4, and 3.3 micronaire (mic., μg/in.) respectively, what would be the theoretical fineness of the cotton in the mix? You need to show your calculations.

3. On a draw-frame or drawing machine, why is it often necessary to adjust the ratch setting according to the fibres to be processed?
4. With reference to the two-zone drawframe in figure 1.18 and assuming a break draft of 1.5 and a main draft of 4. If the average count of the eight input slivers is 12 ktex, what is the count of the single output sliver? If the delivery (front) roller speed is 400 m/min, what would be the approximate speed of the feed (back) rollers?
5. With reference to fibre hooks, explain why two passages of drawing are necessary between cotton carding and cotton combing. You should consider the following points:
   - Hook generation in carding
   - Hook removal during drafting
   - Effect of hook direction on combing

Worsted Processing

Introduction

Long staple fibres are fibres longer than about 2 inches. Fibres such as merino wool, mohair and alpaca fibres are typical long staple fibres. Synthetic staples of similar length are long staple synthetic fibres. Long staple fibres are processed on the worsted processing system mainly, to make worsted yarns.

This topic focuses on the principle and quality of worsted processing of wool fibres.

Objectives

At the end of this topic you should be able to:

- Understand the principles and functions of worsted processing from raw wool to top
- Appreciate the effect of raw wool quality on the quality of tops
- Know the applications of the TEAM formula in top-making
- Appreciate how fibre processing affects fibre properties

Process overview

The worsted industry is more fragmented than the cotton or short staple industry. The processing from greasy wool to worsted yarn is often carried out separately in different mills - early stage processing (ESP) mill, top-making mill and spinning mill. The early stage processor cleans the greasy wool. The top-maker buys the clean wool from the early stage processor and converts the wool into a top (a sliver ready for worsted drawing and spinning). The spinner sources the top from the topmaker and processes it into worsted yarns.

Some mills engage in both early stage processing and topmaking, others are vertically integrated and do the whole processing from greasy wool to yarn. Early stage processing and top-making are also used synonymously to refer to all the greasy wool to top processing stages. Worsted processing utilises relatively fine (< 27 micron) and long (> 45 mm) virgin wool and other long staple fibres. A typical sequence of worsted processing of wool is given in Figure 2.1.

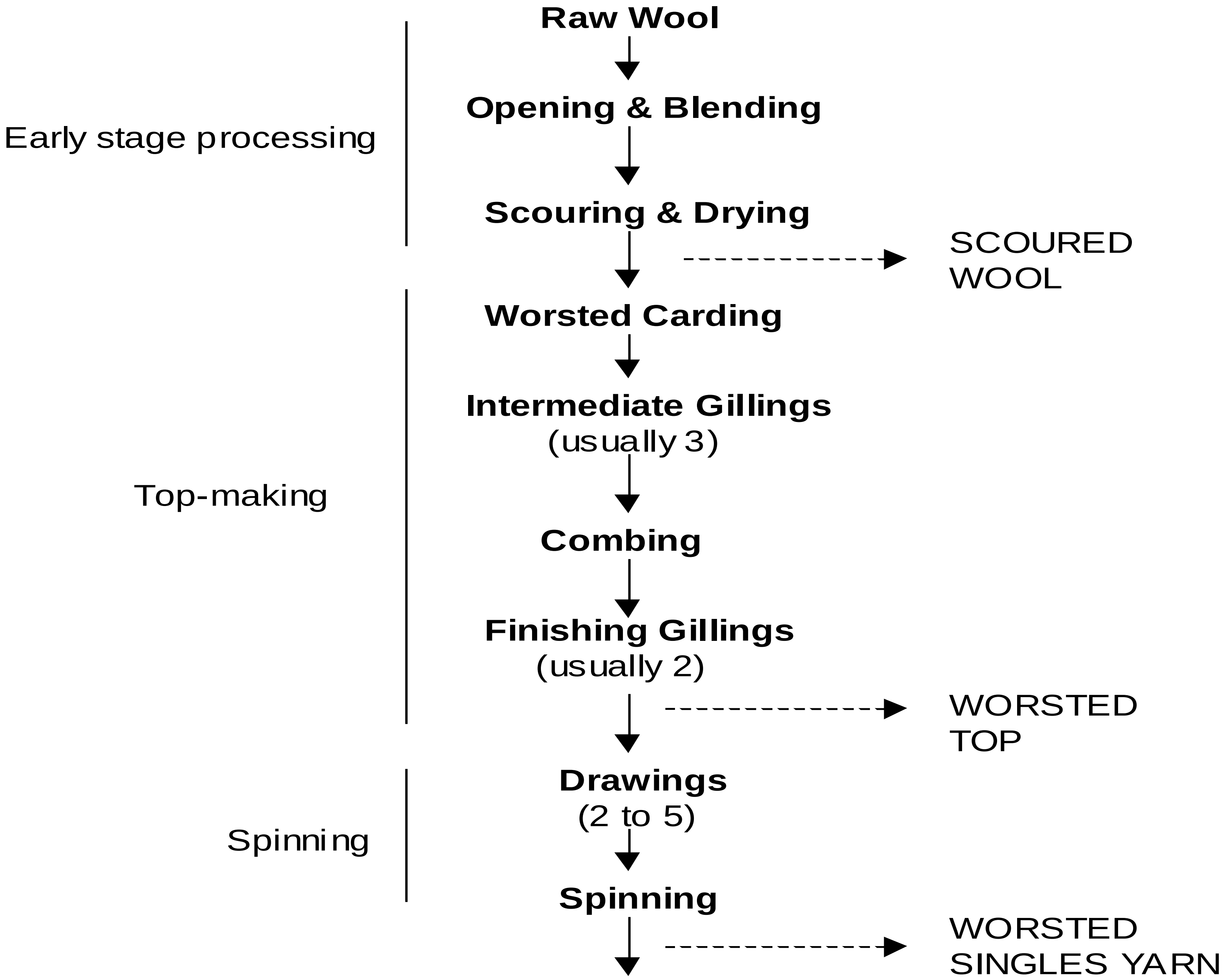


Figure 2.1 A typical worsted processing sequence for wool

Before wool processing can start, we need to first of all source the raw wool. Sourcing the right raw wool is vital and requires a good understanding between the raw wool, wool top, worsted yarn and fabric. Even though raw wool is the starting point for wool processing, the decision to source a certain type of raw wool is governed by the intended end use of the fibre. Fabric requirements govern yarn requirements; yarn requirements govern top requirements, which in turn govern the raw wool specifications. This relationship is represented in Figure 2.2.

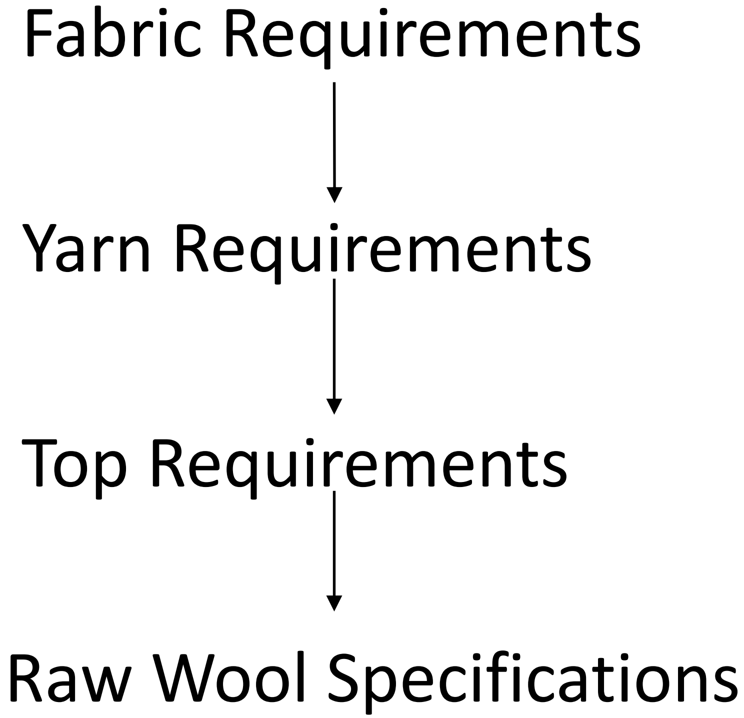


Figure 2.2 End use governs raw wool purchase

Traditionally, translating the end use requirements to raw wool requirements calls for considerable skills and experience. However, tools have been developed in recent years to facilitate this translation in the worsted industry. The notable examples of such tools are TEAM formulae and Yarnspec software developed by the CSIRO Textile and Fibre Technology (formerly known as CSIRO Division of Wool Technology).

The TEAM formulae and applications

- **Introduction**

The bulk of Australian wool clip is now scientifically sampled and the samples are objectively measured before sale for a range of properties. When objective measurements of greasy wool started in Australia in the early 70s, only Yield (i.e. the amount of clean fibre that can be produced from the greasy wool), Vegetable Matters (VM) and Mean Fibre Diameter (in micron) were measured. While these measurements are very important for raw wool sales, they can not be used to adequately predict the processing performance of the measured wool. In the late 70s, technology for additional measurements of raw wool became available.

These include measurements of staple length, staple strength and position of break using the ATLAS instrument developed in CSIRO. The use of these measurement results has become an indispensable tool for modern wool processing mills worldwide. There are three major advantages associated with the use of objectively measured and specified wool:

- Maintaining control of the quality of wool delivered to the mill,
- Monitoring processing performance and quality management in the mill, and,
- Optimising wool blend selection and minimising raw wool cost by taking advantage of the wool price differentials.

To make use of these advantages, the wool processing mills should have some knowledge of the TEAM prediction formulae.

TEAM stands for Trials Evaluating Additional Measurements. These trials were conducted between 1981 and 1988 by the former Australian Wool Corporation, the Australian Wool Testing Authority Ltd (AWTA Ltd) and the CSIRO Division of Wool Technology (now known as CSIRO Textile and Fibre Technology). Over 20 mills in 12 different countries were involved in the trails.

As a result of these trials, a series of prediction formulae (known as the TEAM formulae) were released, which can be used to predict the processing performance of fully measured wool in terms of the following:

- Hauteur
- CV of Hauteur
- Barbe
- Romaine

Hauteur and Barbe are two different measures of the average fibre length. Their calculations may be explained with the simple case of two fibres indicated in figure 2.3. The average length of these two fibres may be different, depending on how we calculate it.

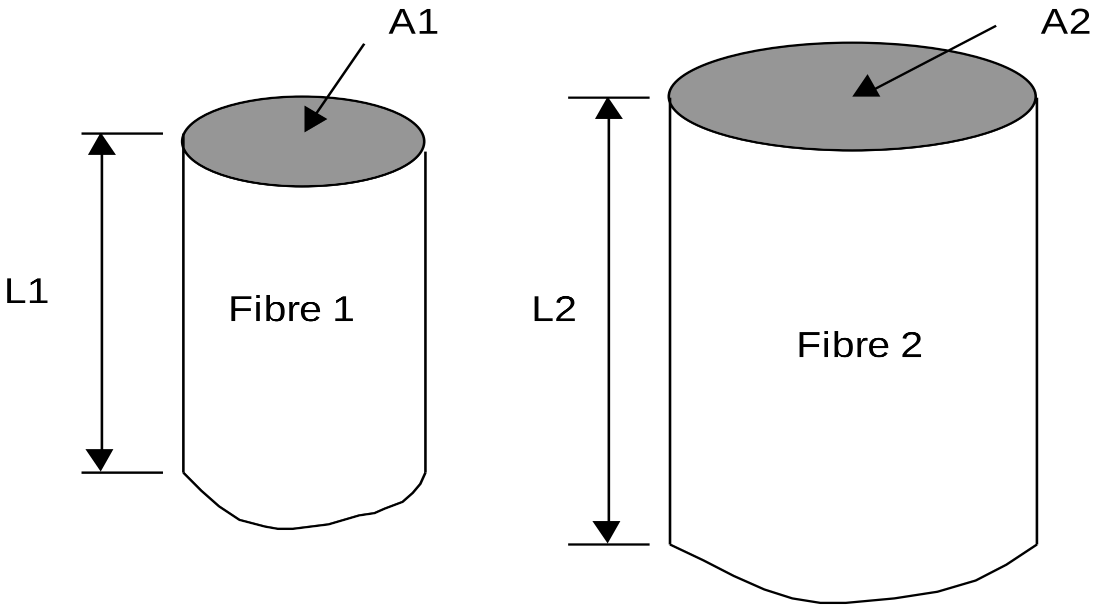


Figure 2.3 A simplified example for calculating the mean fibre length

$$\textit{Numericalmean fibrelength}: \quad L_N = \frac{L1+L2}{2}$$

$$\textit{Crosssectionbiasedmean fibrelength}(\textit{Hauteur}): \quad H = \frac{A1\times L1 + A2\times L2}{A1+A2}$$

$$\textit{Weightbiasedmean fibrelength}(\textit{Barbe}):$$

$$B = \frac{(\rho\times A1\times L1)\times L1 + (\rho\times A2\times L2)\times L2}{(\rho\times A1\times L1) + (\rho\times A2\times L2)} = \frac{A1\times L1^2 + A2\times L2^2}{A1\times L1 + A2\times L2}$$

$$\textit{where } \rho \textit{ is fibre density.}$$

For example, if L1 = 60 mm, L2 = 80 mm, A1 = 300 m2, A2 = 400 m2 , then the above calculations will give: Ln = 70 mm, H = 71.4 mm, B = 72.8 mm.

The numerical mean length is the true average length of the fibres. But it is difficult to obtain in practice. Hauteur length has been the most commonly used in the worsted industry. It can be easily obtained from commercial instruments such as the Almeter and WIRA fibre length meter.

Romaine is the term used in the worsted industry to describe the amount of noil produced during the combing process, expressed as a percentage of the total (noil and combed sliver).

These prediction formulae can be applied to any combing wool with full objective measurements, whether that be individual lots or entire consignments, of wholly measured Australian wool. Computer softwares have also been developed to assist with the calculations of the predicted results.

The general formula for Hauteur

As discussed above, Hauteur is the (cross section biased) mean length of fibres in the wool top (a top is a sliver of parallel fibres, obtained after the processes of scouring, carding and combing of greasy wool). It is normally measured by using an instrument called Almeter. Hauteur value has a significant effect on top price and the subsequent yarn properties. Hauteur has traditionally been estimated subjectively by wool buyers and processors.

However, the TEAM project has demonstrated that the theoretical Hauteur value may be predicted from measurements on raw wool according to the following general formula:

$$H = 0.52\,L + 0.47\,S + 0.95\,D - 0.19\,M^* - 0.45\,V - 3.5$$

where H = Predicted Hauteur (mm)

L = Mean Staple Length (mm)

S = Mean Staple Strength (N/ktex)

D = Mean Fibre Diameter (micron)

M* = Adjusted Percentage of Middle Breaks (%)

3.5 = A Constant

NB 1: The value of M* is determined from the percentage of staples which broke in the middle portion (PM) as displayed on an AWTA Test Certificate for Staple Length and Strength as follows:

for PM values between 0 to 45% then M* = 45
for PM values between 46 - 100% then M* = PM

For example, if a consignment has objective measurements of Mean Staple Length (90mm), Mean Staple Strength (40 N/ktex), Mean Fibre Diameter (21 microns), adjusted Percentage of Middle Breaks (50%), and Mean VM Base (2.0%), then the Hauteur predicted from the general formula is:

H = 0.52 * 90 + 0.47 * 40 + 0.95 * 21 - 0.19 * 50 - 0.45 * 2.0 - 3.5 = 71.7 (mm)

NB 2: The TEAM formula for predicting Hauteur is based on the processing results of 545 consignments combed at 20 different mills worldwide. Raw wool test data for the consignments fell into the following ranges:

Mean Staple Length	59 - 123 mm
Mean Staple Strength	23 - 60 N/ktex
Mean Fibre Diameter	17 - 31 microns
VM Base	0.1 - 10.0%

Application of the above formula to data which falls outside these ranges should be treated with caution.

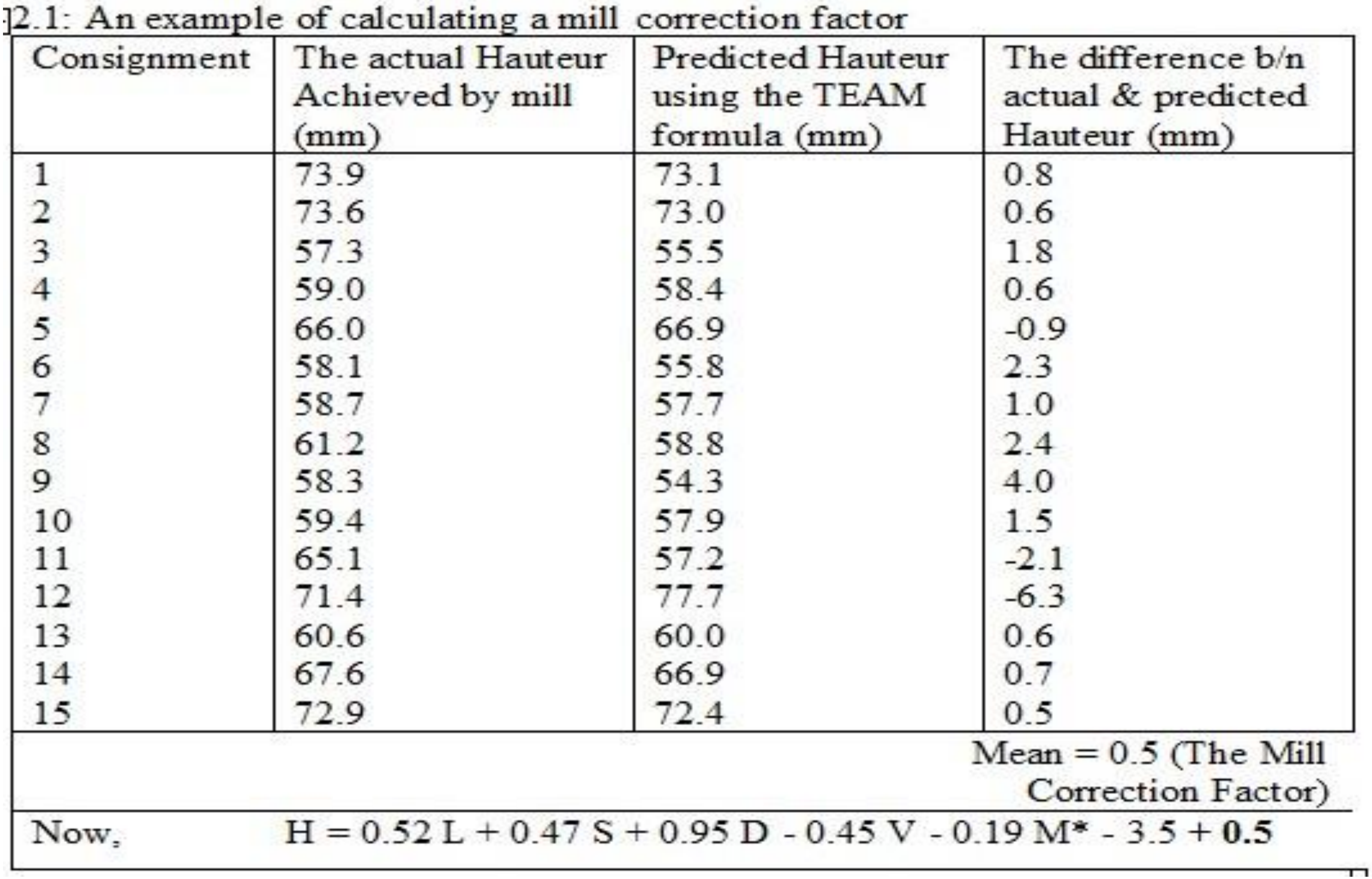
The mill adjustment factor(工厂修正因数)

All wool processing mills are different. They may use different raw materials and have different processing machinery installed. While the general formula for Hauteur gives a satisfactory general prediction for mills, as adjustment to reflect performance for individual mills are often needed, particularly if a mill produces tops that are consistently longer or shorter than the length predicted by the general formula. The TEAM prediction represents the world average of processing performance.

The constant (-3.5) in the TEAM formula can be adjusted when a mill has monitored the processing performance of 10 to 15 consignments. The mean value of the difference between the Hauteur predicted by the TEAM formula and the actual Hauteur achieved can be calculated. This mean value then becomes the "Mill Correction Factor" and is added or subtracted from the constant in the TEAM formula.

If changes are made to the mill processing conditions, such as the installation of new machinery, differences will be expected and alterations to the Mill Correction Factor will be necessary. It is also worth noting that the Mill Adjustment Factors are commercially sensitive, individual traders are unlikely to be advised of them by the commissioning combers.

An example of calculating a Mill Correction Factor is given in Table 2.1 below:



2.1: An example of calculating a mill correction factor

Consignment	The actual Hauteur Achieved by mill (mm)	Predicted Hauteur using the TEAM formula (mm)	The difference b/n actual & predicted Hauteur (mm)
1	73.9	73.1	0.8
2	73.6	73.0	0.6
3	57.3	55.5	1.8
4	59.0	58.4	0.6
5	66.0	66.9	-0.9
6	58.1	55.8	2.3
7	58.7	57.7	1.0
8	61.2	58.8	2.4
9	58.3	54.3	4.0
10	59.4	57.9	1.5
11	65.1	57.2	-2.1
12	71.4	77.7	-6.3
13	60.6	60.0	0.6
14	67.6	66.9	0.7
15	72.9	72.4	0.5
			Mean = 0.5 (The Mill Correction Factor)
Now,	$H = 0.52 L + 0.47 S + 0.95 D - 0.45 V - 0.19 M^* - 3.5 + \mathbf{0.5}$		

Processors can also calculate their own tailor-made 'mill specific prediction formula' using a regression equation based on the greasy wool characteristics found to be the most important for the mill. Any standard computer package containing regression analysis can do this. However, it must be stressed that new formulae should only be developed on large databases. When a small database is available, the above approach for calculating the Mill Correction Factor should suffice.

TEAM formulae for the predictions of CV of Hauteur, Romaine & Barbe

Besides the formula for the prediction of Hauteur, the TEAM projects also developed prediction formulae for the Coefficient of Variation of Hauteur, the Romaine and the Barbe.

The CV of Hauteur (CVH) is an important feature of the top length distribution, since it may affect the subsequent drafting and spinning performances. Romaine is the term used to describe the quantity of noil expressed as a percentage in relation to the combined quantity of top and noil. It reflects the combing efficiency. Barbe is a weight biased measurement of fibre length in the top and is not as widely used as Hauteur.

The three prediction formulae are:

$$CVH = 0.12\,L - 0.41\,S - 0.35\,D + 0.20\,M^* + 49.3$$

$$Romaine = (-0.11)\,L - 0.14\,S - 0.35\,D + 0.94\,V + 27.7$$

$$Barbe\ (B) = 0.73\,L + 0.32\,S + 0.96\,D - 0.51\,V - 0.086\,M^* - 5.3$$

The symbols L, S, D, M* and V are as previously defined for TEAM Hauteur Formula. The above three formulae can also be adjusted to any particular mill in the same way as the TEAM Hauteur Formula, by adding or subtracting a mill adjustment factor to the constants, when appropriate.

It is also worth noting that the TEAM formulae have been developed for general use and therefore do not take into account variations in processing performance between and within specific mills. If the predictions are outside the following ranges, care must be taken in interpreting the prediction results:

Hauteur: Less than 55 mm and greater than 80 mm
CVHa: Less than 40% and greater than 55%
Romaine* Less than 3% and greater than 12%

In summary, the TEAM project has demonstrated the importance of additional measurements on raw wool. Without these additional staple measurements, the prediction of Hauteur and Romaine are not as accurate and it is impossible to predict CVHa or other top length distribution specifications important to the spinner. Many topmakers and spinners worldwide are willing to pay premiums to have their raw wool measured for staple length, strength and position of break. Wool users, whether mills, exporters, or traders, should maintain a record of the greasy wool measurement data and the difference between the processing characteristics predicted by the TEAM formulae and those actually achieved for each processing consignment. By doing this, a 'mill specific' database can be built and used to improve the predictions for that mill.

Applications of TEAM formulae

The TEAM formulae have a number of applications. The major ones include assisting mill quality control and raw wool specification.

When a wool processing mill uses fully measured Australian wool, the mill performance can be monitored with the help of TEAM formulae. For instance, the differences between actual and predicted Hauteur of the tops produced in a mill can be plotted on a time-series graph. By setting boundary limits for the size of the deviations, a control chart can be established to indicate whether the mill's topmaking process is 'in control'.

Another impartant application of TEAM is in assisting with raw wool specification. As mentioned in the overview, producing the right worsted yarn requires the right tops, which in turn require the right raw wool. To explain this point, let's assume that we (a spinner) need to spin 2/52 Nm weaving yarns for a fabric manufacturer. The question is what is the right raw material for efficient spinning of this yarn?

To answer this question, we need to get the right tops first. The two critical parameters for a wool top are the average fibre diameter and length. Determining the average fibre diameter is relatively easy, because the fibre should be fine enough to ensure adequate average number of fibres in yarn cross section. As discussed in the module on yarn evenness, the minimum number of fibres in the cross section of a worsted yarn should be about 40. Below this limit, yarn quality drops rapidly and spinning becomes inefficient due to increased ends-down. Table 2.2 gives the approximate diameter range used in majority of commercial weaving and knitting yarns, and the corresponding average number of fibres in yarn cross section.

Table 2.2: Choice of average fibre diameter for weaving and knitting yarns

Weaving Yarns		
Count (Nm) (Tex)	Approximate diameter or micron range for majority commercial yarns	Average No of fibres in singles yarn cross section
72/2	18 - 18.5	39 - 37
R28/2	19 - 20	40 - 36
64/2	20.5 - 21.5	42 - 38
R32/2	21 - 21.5	43 - 41
52/2	21.5 - 24	50 - 40
R38/2	23 - 25	48 - 41
48/2	25 - 26	46 - 42
R42/2		
40/2		
R50/2		
36/2		
R56/2		
32/2		
R62/2		

Knitting Yarns		
20/2	≤ 25	≥ 73
R100/2	≤ 23.5	≥ 59
28/2	≤ 22	≥ 53
R72/2	≤ 21.5	≥ 41
36/2	≤ 19.5	≥ 40
R56/2		
48/2		
R42/2		
60/2		
R34/2		

Note:

1. Knitting yarns generally use finer wools than weaving yarns of equivalent yarn counts, due to product aesthetic requirements, lower spinning twist, shorter fibre length, and the need to maintain an acceptable spinning efficiency.
2. The average number of fibres (N) in yarn cross section can be calculated from the average fibre diameter (D) and yarn count (tex):

$$N = \frac{917 \times tex}{D^2}$$

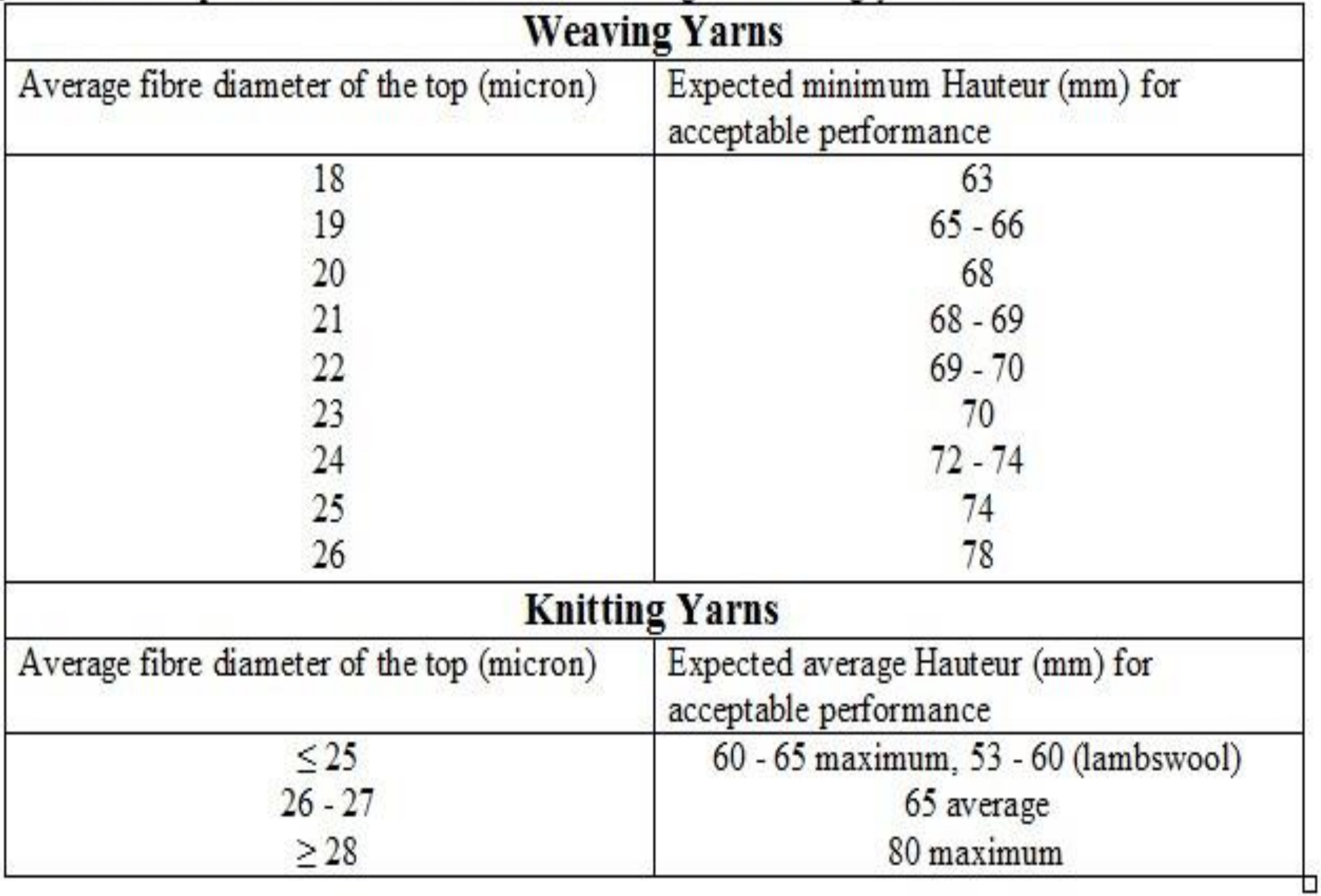
So for a 52/2 Nm weaving yarn, if we wish to have 40 fibres on average in the singles yarn cross section, then the average diameter of the wool should be:

$$D^2 = \frac{917 \times 19.2}{40},$$

$$D = 21(micron)$$

Now that the average fibre diameter is decided, the appropriate Hauteur (mean fibre length) of the top is needed. For this purpose, we may check previous record as to the likely Hauteur value for a given fibre diameter (micron) processed on our machinery. In the absence of previous record, experience values given in Table 2.3 can be used as a starting point.

Table 2.3: Experience Hauteur values for weaving and knitting yarns



<table>
<tr><th colspan="2">Weaving Yarns</th></tr>
<tr><td>Average fibre diameter of the top (micron)</td><td>Expected minimum Hauteur (mm) for acceptable performance</td></tr>
<tr><td>18</td><td>63</td></tr>
<tr><td>19</td><td>65 - 66</td></tr>
<tr><td>20</td><td>68</td></tr>
<tr><td>21</td><td>68 - 69</td></tr>
<tr><td>22</td><td>69 - 70</td></tr>
<tr><td>23</td><td>70</td></tr>
<tr><td>24</td><td>72 - 74</td></tr>
<tr><td>25</td><td>74</td></tr>
<tr><td>26</td><td>78</td></tr>
<tr><th colspan="2">Knitting Yarns</th></tr>
<tr><td>Average fibre diameter of the top (micron)</td><td>Expected average Hauteur (mm) for acceptable performance</td></tr>
<tr><td>≤ 25</td><td>60 - 65 maximum, 53 - 60 (lambswool)</td></tr>
<tr><td>26 - 27</td><td>65 average</td></tr>
<tr><td>≥ 28</td><td>80 maximum</td></tr>
</table>

From this Table, a Hauteur value of at least 68 to 69 mm is necessary for the 21 micron wool. If our machinery is in good condition, the minimum Hauteur can be used. Otherwise, higher Hauteur values should be used to ensure efficient spinning. For the current example, we can set the Hauteur value at 70 mm.

By now we know that to spin a 2/52 Nm weaving yarn, the top specifications should have an average micron value of 21, and a Hauteur value of 70 mm. The next step is to translate these values into raw wool specifications. Again determining the micron of the raw wool is the first necessary step. In a typical top-making process, it is normal that the average fibre diameter increases by about 0.3 micron after top-making, the reason for this is briefly discussed in the section on combing. Again an individual mill's past performance should be looked at in terms of diameter increase (occasionally, fibre diameter increase can be up to 1 micron). Keeping this in mind, the average diameter of the raw wool should be finer than that of the top.

We can use 20.7 micron for this example. Now that the average micron for the raw wool is determined, we need to know other raw wool characteristics, such as staple length, staple strength etc. This is where the TEAM formulae play an important role. Using the TEAM formulae, we can play with different combinations of values for the parameters in the TEAM prediction formula for Hauteur, such as different staple length, staple strength, mid breaks etc, to get the right Hauteur value (70 mm in this example).

One possible combination is:

Mean fibre diameter (D): 20.7 micron (already determined)

Mean staple length (L): 87 mm

Mean staple strength (S): 40 N/tex

Vegetable matter base (V): 1%

Percentage of mid breaks: 50%

Using the TEAM formula for Hauteur,

$$H = 0.52\ L + 0.47\ S + 0.95\ D - 0.19\ M^{*} - 0.45\ V - 3.5$$

$$H = 0.52 \times 87 + 0.47 \times 40 + 0.95 \times 20.7 - 0.19 \times 50 - 0.45 \times 1 - 3.5 = 70.3\ (\text{mm})$$

It should be pointed out here that the Hauteur value predicted by the TEAM equation is an average value. This means half of the actual Hauteur values may fall above the prediction, and the other half fall below prediction. In other words, there is a 50% probability for the actual Hauteur to be less than that required. This is not an acceptable situation. In practice, it is common to ensure that the raw wool purchased will perform better than predicted, so that there is only about 5% chance of not meeting the requirement.

It should also be pointed out though that in addition to average fibre diameter and fibre length, fibre diameter and length variations, short fibre content in the top, are also important considerations. Furthermore, the amount of noil produced during combing is another important consideration. The value of combing noil is only about 30% of the value of a top. If we apply the TEAM formulae for Hauteur CV and for Romaine to our example, we get:

$$CVH = 0.12\ L - 0.41\ S - 0.35\ D + 0.20\ M^* + 49.3$$
$$= 0.12 \times 87 - 0.41 \times 40 - 0.35 \times 20.7 + 0.20 \times 50 + 49.3$$
$$= 46.1\ (\%)$$

$$Romaine = (-0.11)\ L - 0.14\ S - 0.35\ D + 0.94\ V + 27.7$$
$$= (-\ 0.11) \times 87 - 0.14 \times 40 - 0.35 \times 20.7 + 0.94 \times 1 + 27.7$$
$$= 6.2\%$$

The CV of Hauteur (CVH) may affect drafting performance. Too high a CVH may lead to poor evenness of yarns. For this reason, the experiences have shown that CVH value should be less than 50%. The 46.1% CVH for our example is below this figure. If we wish to have a lower CVH than 46.1%, we can change some parameter in the CVH formula, bearing in mind that any change will also affect the predicted Hauteur and Romaine values. As indicated earlier, computer packages are available to assist with these calculations.

On the basis of this information, a specification of the raw wool required for producing the 2/52 Nm weaving yarn can be worked out. With a proper specification, we will get the right raw materials. Once we get the right raw materials, we can start the processing. The first processing stage is scouring, which is discussed next.

Scouring(洗毛)

A number of processes are carried out in a scouring mill, including:

- preparation of wool for scouring by opening and blending,
- scouring itself, and,
- drying of scoured wool.

Raw wool contains a number of impurities. Some of the impurities are removed in scouring, others are removed in further processing. Table 2.4 lists the impurities that are found in raw wool, and the ways of removing these impurities. Figure 2.4 gives the average compositions of Australian merino and crossbred fleeces.

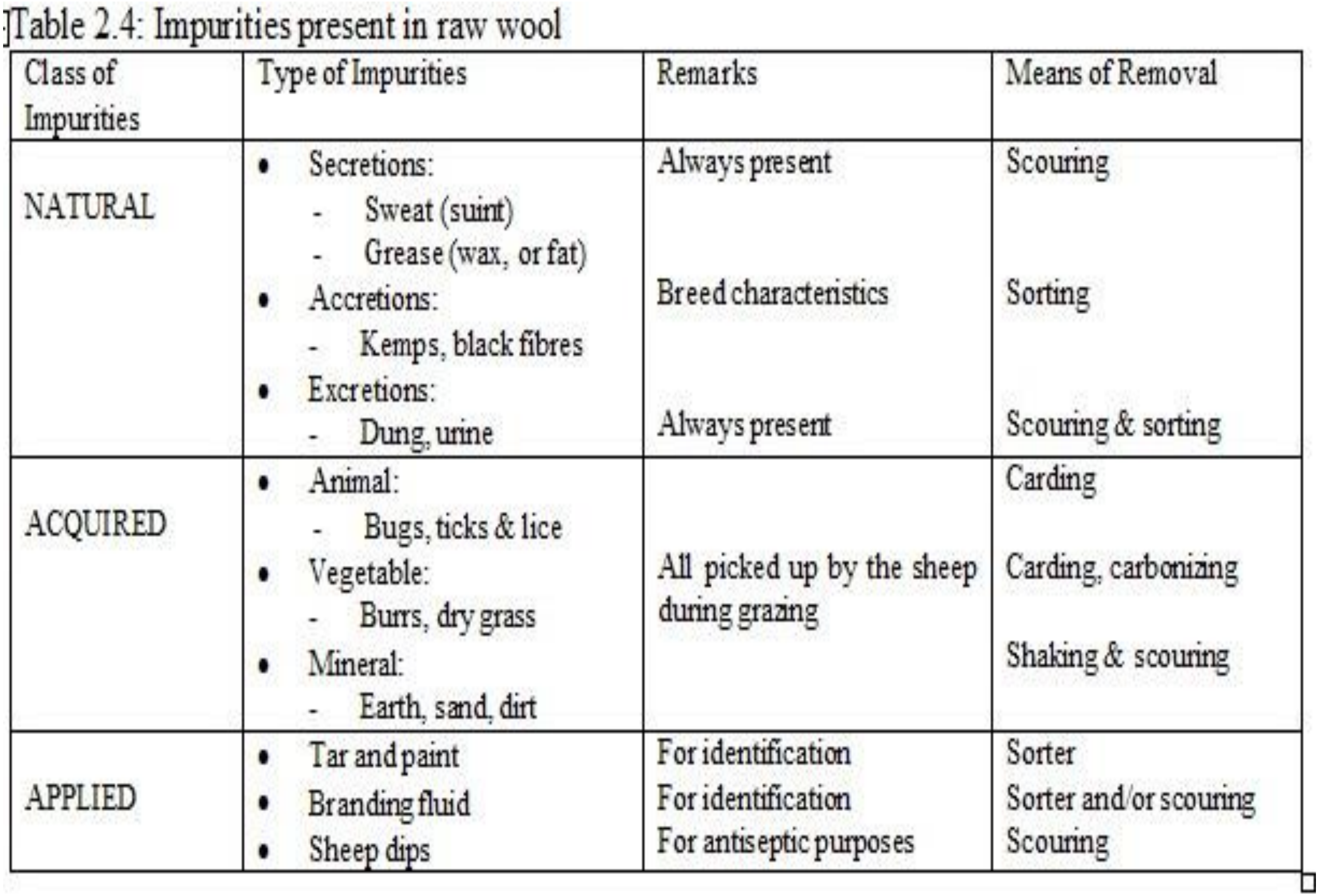


Table 2.4: Impurities present in raw wool

Class of Impurities	Type of Impurities	Remarks	Means of Removal
NATURAL	- Secretions: - Sweat (suint) - Grease (wax, or fat)	Always present	Scouring
	- Accretions: - Kemps, black fibres	Breed characteristics	Sorting
	- Excretions: - Dung, urine	Always present	Scouring & sorting
ACQUIRED	- Animal: - Bugs, ticks & lice	All picked up by the sheep during grazing	Carding
	- Vegetable: - Burrs, dry grass		Carding, carbonizing
	- Mineral: - Earth, sand, dirt		Shaking & scouring
APPLIED	- Tar and paint	For identification	Sorter
	- Branding fluid	For identification	Sorter and/or scouring
	- Sheep dips	For antiseptic purposes	Scouring

Figure 2.4 Average composition of a Merino fleece (a) and Australian crossbred (b) (Humphries 1996, p.90 [courtesy of International Wool Secretariat])

The main objectives of scouring are:

- To remove various impurities (grease, suint, mineral) from wool in such a way that the scoured wool is clean, full and open (with little felting of wool).
- To leave a small amount (about 0.5%) of residual grease on the wool to facilitate further mechanical processing.

Wool grease and suint are the key impurities removed during scouring in the so called aqueous emulsion scouring process using detergent and hot water. Grease can also be removed by dissolving in organic solvent using the solvent scouring process. But before we talk about the actual scouring processes, we need to understand the chemistry of these impurities.

- **The chemistry of impurities(杂质)**

◆Suint

Suint consists of potassium salts of the various lower fatty and amino acids, plus some inorganic salts. Like the table salt used for cooking, suint is soluble in water, particularly warm water (~ 30oC). So removal of suint in aqueous scouring is not a problem.

◆ Grease/Wax

Grease is a mixture of higher fatty acids (CnHmCOOH, or RCOOH) and alcohols. There is about 2 - 15% free fatty acid in raw grease. At pH > 9, free fatty acid can be saponified (turned into soap by decomposition with alkali). The Saponifying (soap making) process is indicated below:

$Na_2CO_3 + 2H_2O \rightarrow 2NaOH + H_2CO_3$

$NaOH + RCOOH \rightarrow H_2O + RCOONa$ (soap!)

Grease has a relatively low melting point (38 to 43°C). In aqueous scouring, it is important to raise the liquor temperature above this value to facilitate grease removal. Since grease usually forms a stable film around fibre surface. The attraction between grease and wool needs to be reduced to dislodge grease from fibre surface. In aqueous emulsion scouring, this is achieved with the help of scouring agents such as detergent

◆ Vegetable matter (VM)**(草杂)**

Vegetable matter is cellulose material. Scouring removes very little vegetable matter from wool. A small amount of VM is removed during the pre-scour opening, and the rest is removed in the post-scour carding and combing.

- **The scouring agents(洗涤剂)**
  - Detergent (Natural or Synthetic)

Detergents are surfactants or surface-active agents. Surfactant molecules have a hydrophilic head and a hydrophobic tail as indicated in figure 2.5 below.

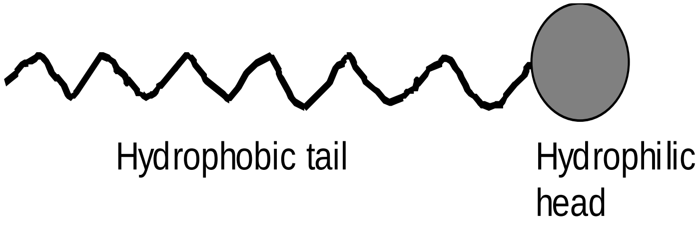


Fig. 2.5: The molecule of a surfactant with a hydrophilic head and a hydrophobic tail

In the presence of an interface (eg. air/water, grease/water), the surfactant molecules are adsorbed at the interface due to differing polarities of head and tail. This then lowers the interfacial surface tension. The importance of reducing interfacial surface tension in scouring will be discussed later.

The two main types of detergent are natural soap and synthetic detergent.

Natural soap is made from action of alkali with a fatty acid. It can also be created by the saponifying process in scouring, as indicated in the section on the chemistry of impurities. The water for wool scouring should be soft water. Synthetic detergents are not destroyed by lime salts. They can be used under neutral pH (so less wool damage) but scouring is more efficient in slight alkalinity. Synthetic detergents have very high detergent efficiency, even at low concentrations (when scouring fabrics in the finishing stage, this may be a drawback. Because a thorough degreasing often leads to a worsening fabric handle. Most modern scouring mills use synthetic detergents rather than natural soaps.

- Water

The water used in aqueous scouring should be of minimum hardness, particularly when natural soap is used as the detergent. Hard water containing calcium salts (lime) will reduce the effectiveness of soap:

soap + calcium salts (lime) = lime soap (insoluble!)

The insoluble lime soap can adhere firmly to wool and cause difficulty in the subsequent carding, combing and dyeing.

Aqueous wool scouring consumes a large quantity of water. One kilo of greasy wool may require up to 20 litres of water for scouring. If a scour has a capacity of 1,200 kg/hour, then a staggering 24,000 litres of water will be consumed in every hour of the scour's working life. Researchers and industrialists have put considerable effort into reducing water consumption in scouring and treating scouring effluent.

◆Alkali**(碱)**

The addition of alkali adds to the efficiency of scouring. It is usually in the form of sodium carbonate (soda ash) rather than caustic alkali, since caustic alkali attacks wool. As mentioned before, alkali reacts with the fatty acid (in grease) to produce soap in scouring.

- **The principle of aqueous emulsion(水乳状液) scouring**

  As mentioned earlier, aqueous scouring removes suint and grease mainly from wool, and suint removal is relatively easy, because it is soluble in water. Grease removal is more complicated, and this section focuses on how grease gets removed from wool in scouring. The role played by detergent is highlighted in this section. Generally speaking, there are three stages involved in grease removal during aqueous scouring.

Stage 1

This stage has the following functions:

- Wet out greasy wool
- Raise temperature above grease melting point
- Add alkali (demands of wool, saponification, optimum scouring pH)
- Deliver detergent molecules to fibres by liquor flow and diffusion

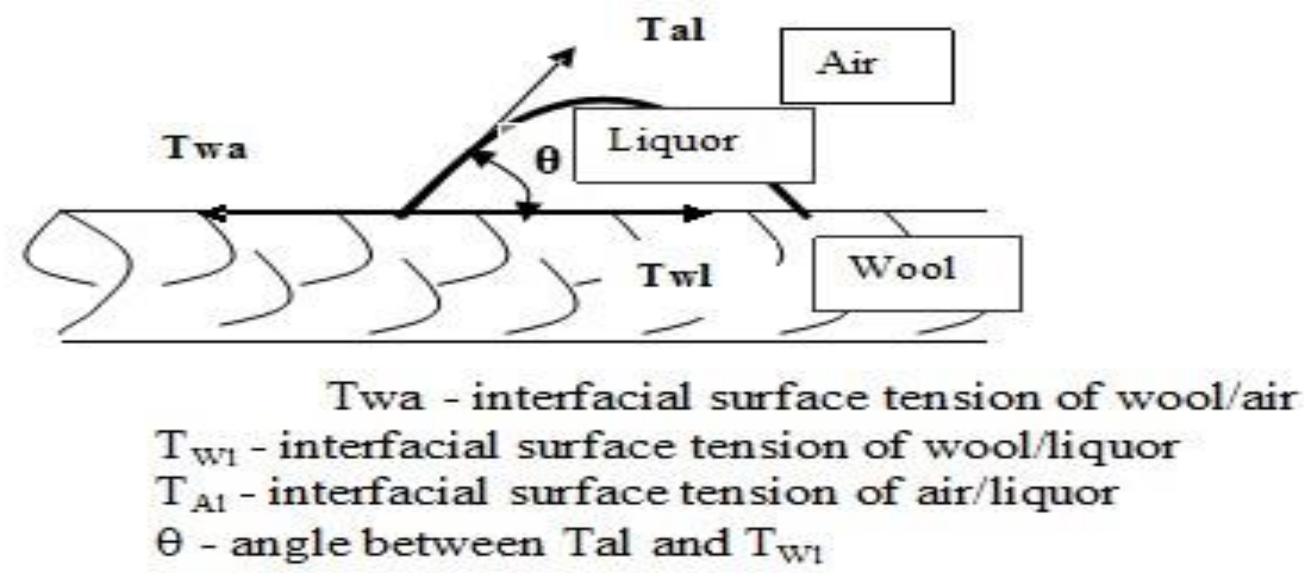
Wetting is the first necessary step for aqueous scouring. The more water molecules on fibre surface, the better the fibre wetting. How easily a greasy wool can get wetted depends upon the fibre/water/air interfacial surface tensions. Ironically, the wettability of water on wool textiles is quite poor. When a drop of water is placed on a surface of wool fibres, the water drop does not spread out on the surface. The attraction between molecules in the water drop is quite strong, which tends to keep the water molecules together in a ball shape. To increase the wettability of water, its surface tension needs to be reduced so that the water can spread out on the fibre surface to achieve good wetting of the fibre.

Figure 2.6 depicts poor and good wetting behaviour of water on a surface.

(poor wetting) **(good wetting)**

Figure 2.6 Poor and good wetting behaviour of water on a surface

In relation to scouring greasy wool, we are looking at a wool/liquor/air system as shown in figure 2.7 below



Twa - interfacial surface tension of wool/air
T_{Wl} - interfacial surface tension of wool/liquor
T_{Al} - interfacial surface tension of air/liquor
θ - angle between Tal and T_{Wl}

Figure 2.7 Wetting the wool fibre with a drop of liquor - the wool/liquor/air system

In equlibrium, the three interfacial surface tensions should be balanced. We have

$$T_{wa} = T_{Wl} + T_{al} * \cos\theta, \quad \cos\theta = \frac{T_{wa} - T_{Wl}}{T_{al}}.$$

This simple relationship can be used to explain how detergent helps the wetting process. Detergents are surfactants, which have the power of reducing surface tension. When detergent is added to the liquor, it greatly reduces the interfacial surface tension between the liquor and its contact surfaces, such as air and wool in this case. Therefore, with the addition of detergent, both Twl and Tal will be reduced. According to the above equations, should decrease when Twl and Tal reduce. A lower means the water drop is more spread out on the wool fibre, hence better wetting. Therefore, from the change in , we can tell how detergents help to wet the wool fibres. In household washing, if you add detergent to the water in the washing machine and then put the clothing items in, the clothing items will get immersed into the water more quickly than when there is no detergent in the water.

Stage 2

This is the key stage, and has the following functions:

- Form surface film of detergent molecules
- Gather grease into droplets
- Sweep droplets from fibre by liquor flow

In this stage, we are looking at a grease/wool/liquor system as shown in figure 2.8 below.

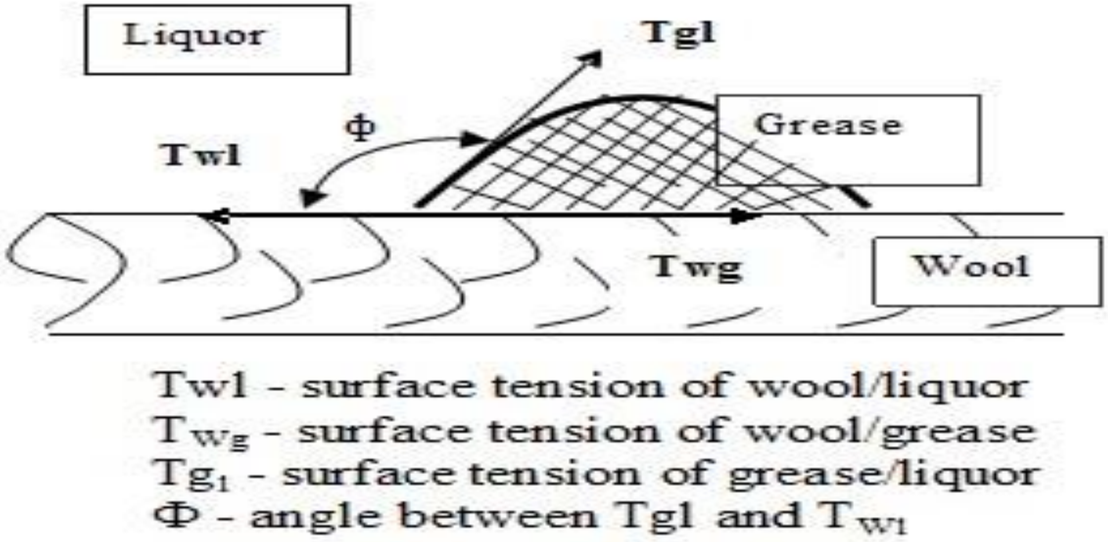


Figure 2.8 Removal of grease from wool - the grease/wool/liquor system

Again, in equlibrium, we have

$$T_{wl} = T_{wg} + T_{gl} * \cos(180 - \phi), \quad \cos\phi = \frac{T_{wg} - T_{wl}}{T_{gl}}.$$

In the presence of detergent (surfactant) in the liquor, both Twl and Tgl will be reduced. According to the above equations, cosϕ should increase (and ϕ should decrease) when Twl and Tgl reduce. A gradually reducing ϕ would mean the grease is rolling up as droplets. When ϕ becomes zero, the grease ball would come off the wool fibre easily with the help of liquor flow. When the grease droplets are detached from the wool, they are surrounded by surfactant molecules. The hydrophobic tails of the surfactant molecules will stick to the grease, while the hydrophilic heads will stay in the liquor. In addition, the like-charged hydrophobic heads on the surfaces of the grease droplets will be mutually repulsive. This keeps the grease droplets separate and suspended in the liquor, without aggregating and re-depositing back onto the fibre surface.

The grease removal process can also be described without using the force balance equations given above. When the scouring liquor containing surfactant molecules comes in contact with grease particles on fibre surface, the water-hating tails of surfactant molecules will compete for places in the grease, because they don’t like water molecules in the liquor. The competition gets tougher and tougher as more and more surfactant molecules try to stick their tails into the oil. They only way of easing the tension of competition is to create more surface of grease, and the only way of doing this is by breaking the grease apart and lifting the grease away from fibre surface gradually.

Once removed from the fibre surface, the grease will be surrounded by the surfactant molecules with the tails inside the grease. In the mean time, the fibre surface originally occupied by the grease will now be occupied by the surfactant molecules, again with their tails sticking to the fibres and heads inside the liquor. The like-charged heads on the fibre surface and on the grease surface repel each other so they try to stay away from each other, thus preventing the grease from being re-deposited on the fibre surface. Similarly, the grease particles broken apart by the surfactant will stay apart as well. Therefore, after scouring, the scouring liquor becomes an emulsion of suspended oil or grease particles, which can be easily removed by rinsing. For this reason, aqueous scouring is also known as emulsion scouring or aqueous emulsion scouring. In other words, surfactant helps to emulsify the oil or grease to facilitate its removal. Similar principle applies to house-hold washing.

The processes of grease or oil removal with surfactant are illustrated below in Figure 2.9.

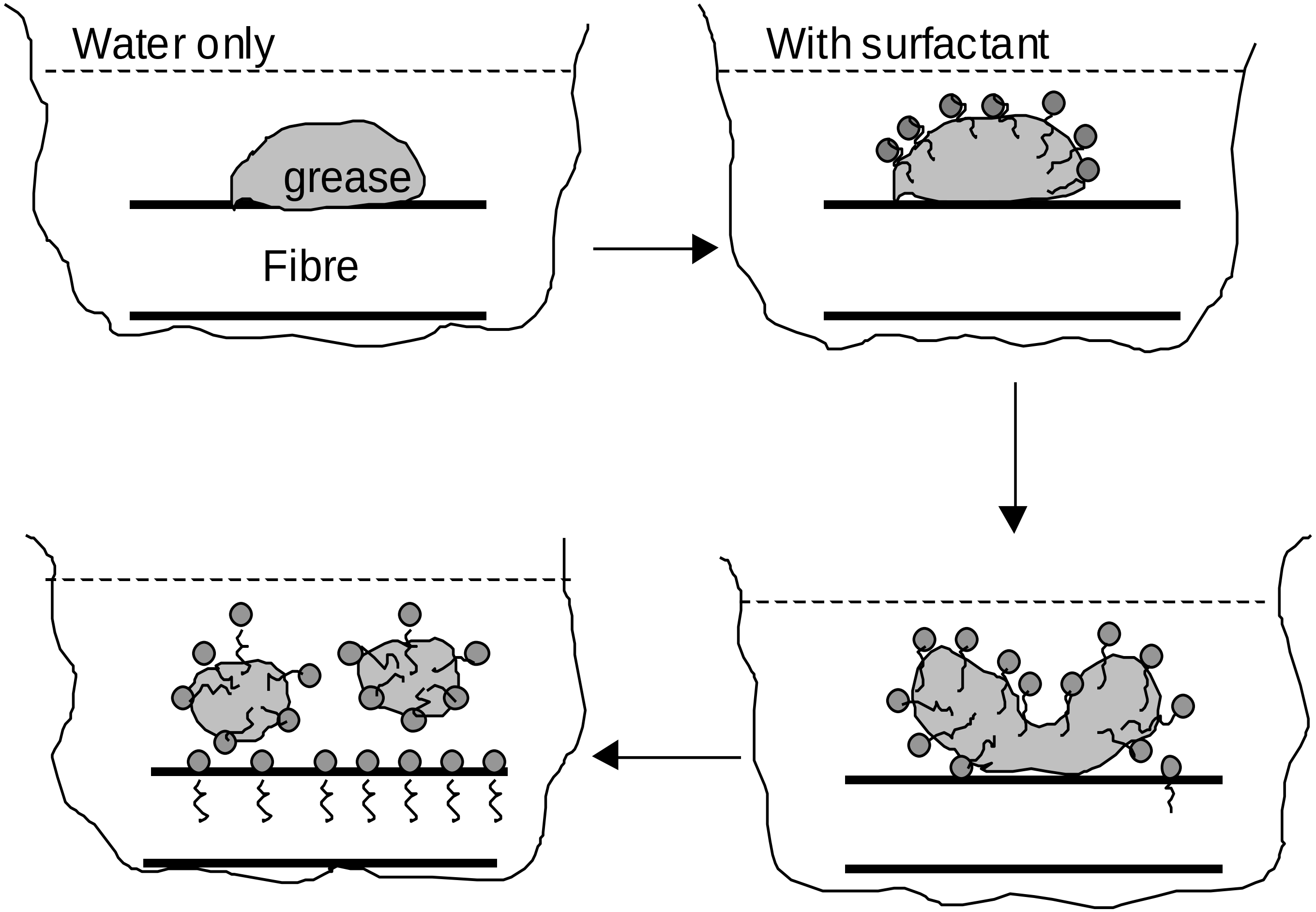


Figure 2.9 The process of grease removal from wool

Stage 3

This is the final stage which has the following functions:

- Remove excess detergent and alkali from wool
- Remove contaminants from liquor

Rinsing with fresh water achieves the first function. Removing contaminants from liquor requires complex effluent treatment system. In fact, a well-known dilemma of wool scouring is the environment friendliness-versus-cost compromise.

- **Commercial aqueous scouring systems**

1.The basic configuration

In a typical process of aqueous emulsion scouring, 5 or 6 scouring bowls are used. Figure 2.10 gives a simplified representation of a 6-bowl aqueous wool scouring process.

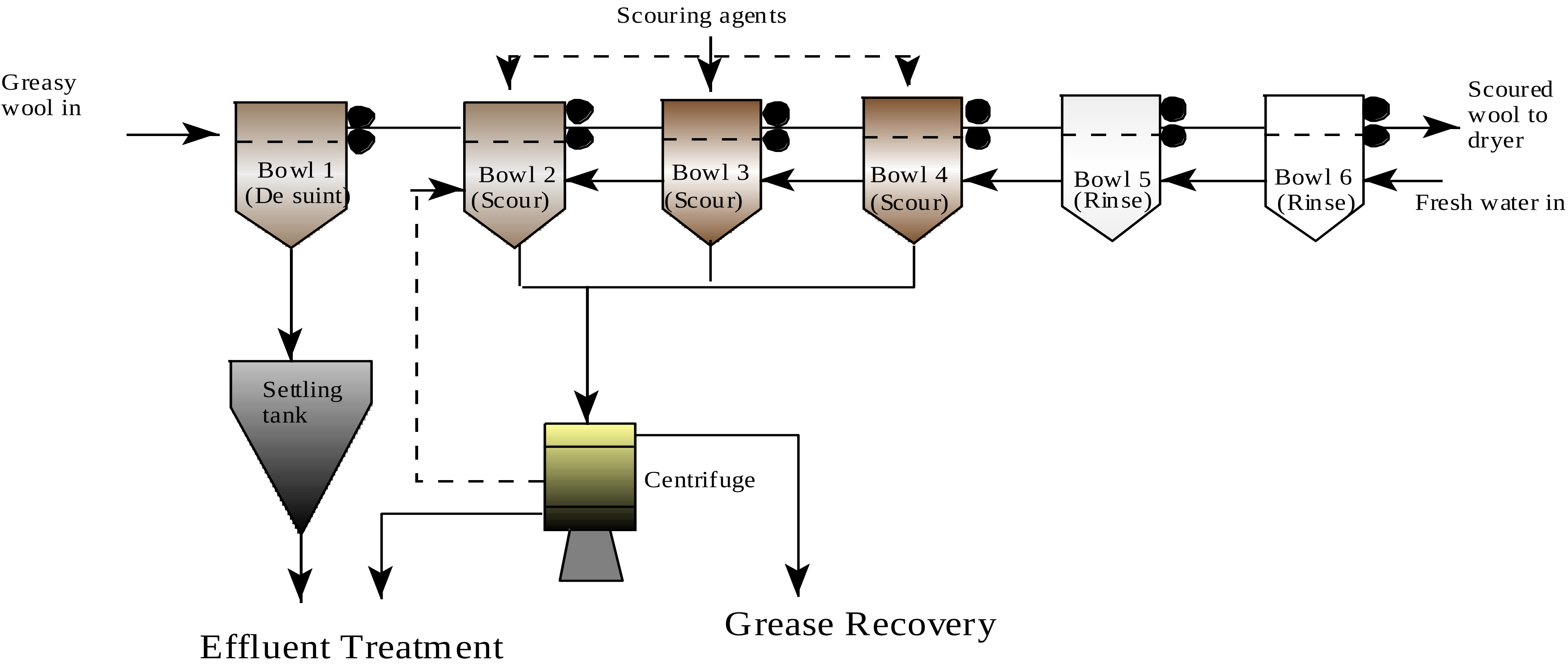


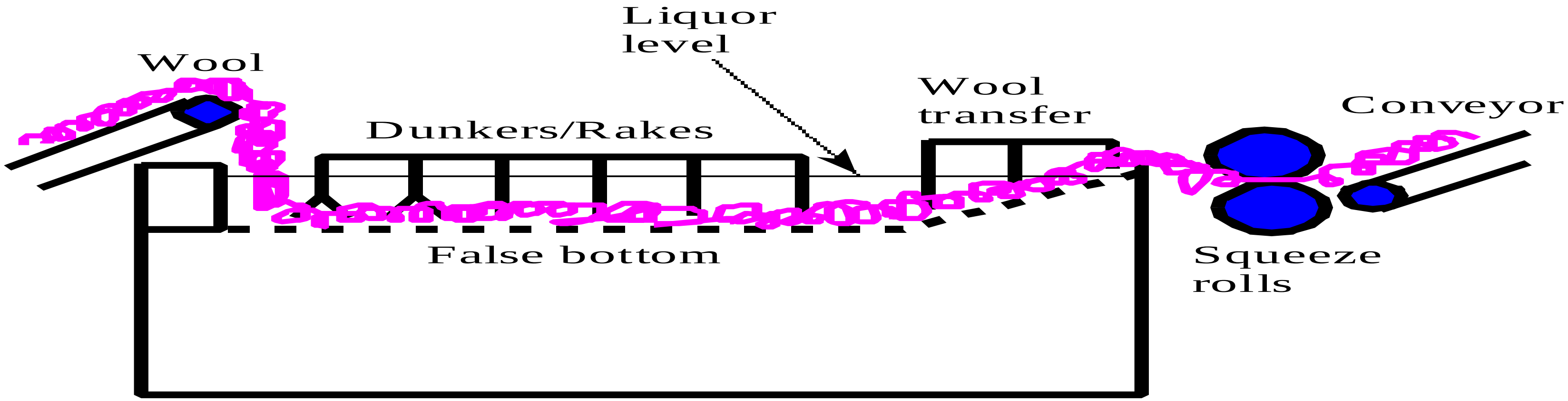
Figure 2.10 A 6-bowl aqueous scouring process

The first de-suint bowl is used to remove water-soluble contaminants such as suint (or sheep sweat) from the wool. The next three bowls contain hot water, detergent and alkali for grease removal, while the remaining two bowls contain clean water for rinsing. Fibres are propelled through each bowl and there is a pair of squeeze rollers between the adjacent bowls. Because of the scale structure on the wool surface, excessive agitation of wool during scouring will lead to felting of wool, which in turn will lead to increased fibre damage during the subsequent processes, carding process in particular.

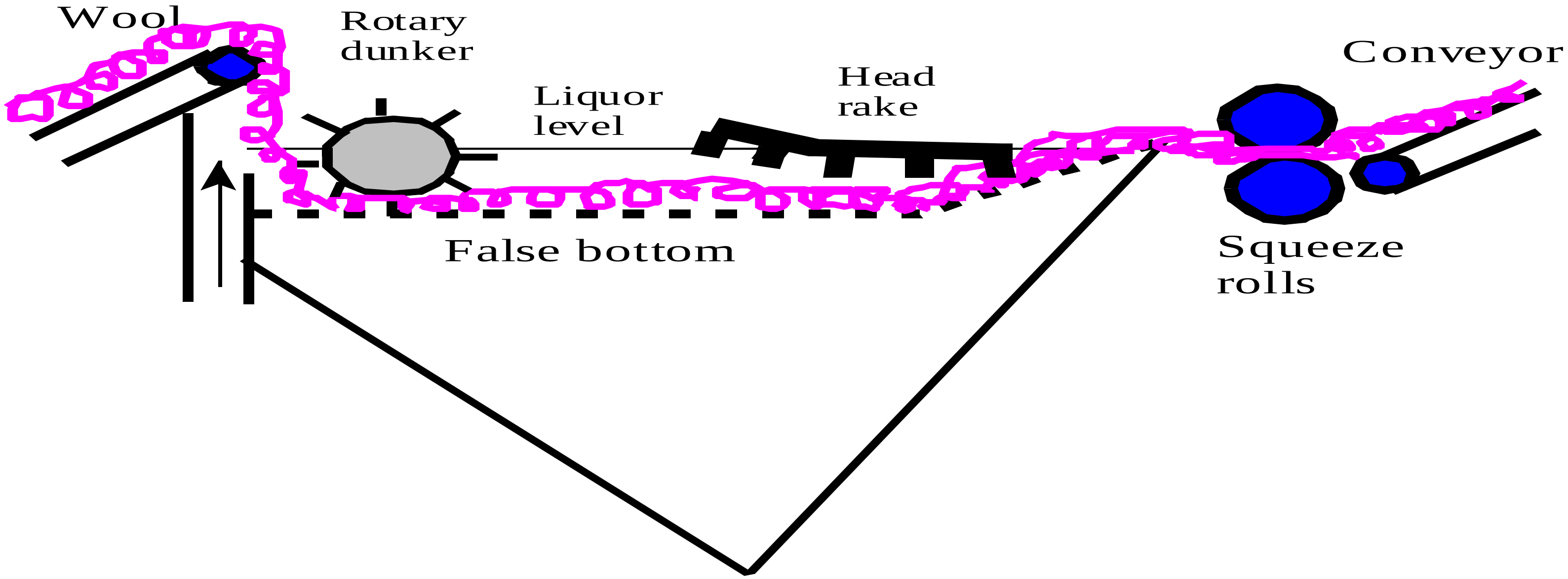
Fresh water is introduced from the last bowl for rinsing, and flows backward to the scouring bowls ('counter-current' flow). The water temperature in the three scouring bowls is usually set at about 55 to 60^{O}C, with the temperature in the rinsing bowls set at about 45 to 50 ^{O}C.

2.Scouring bowls

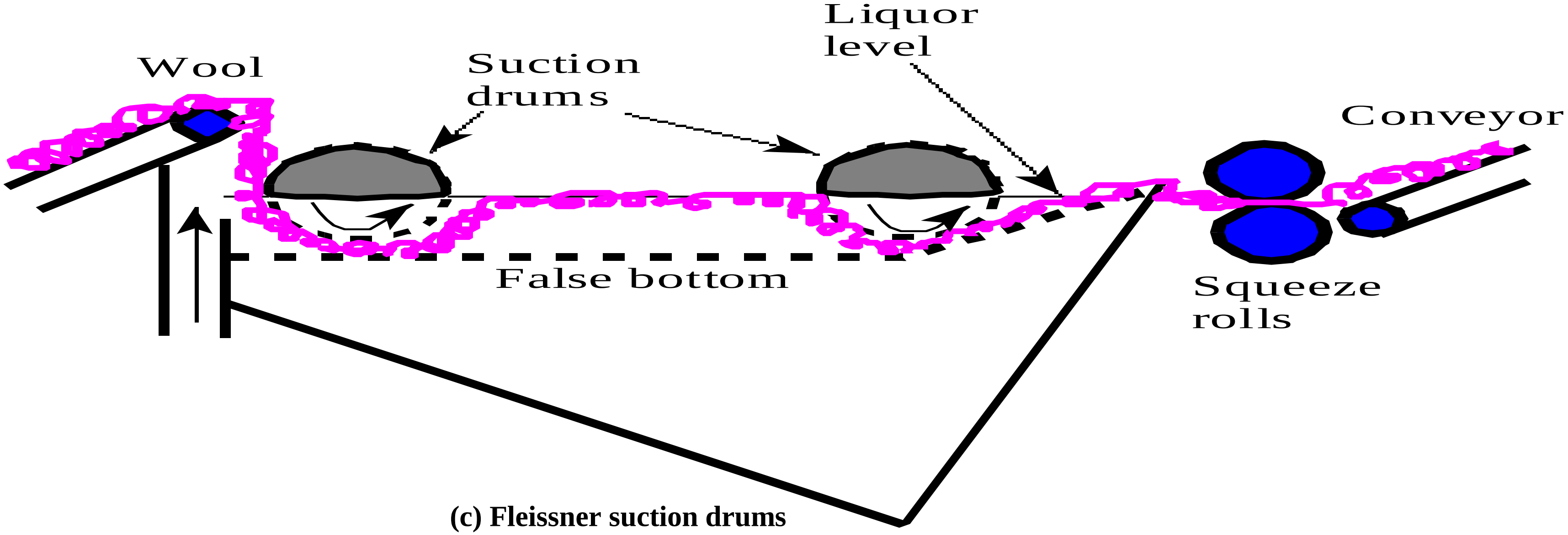
Three types of scouring bowls used in the industry are given in figure 2.11.



(a) Conventional long bowl



(b) WRONZ Mini-bowl



(c) Fleissner suction drums

The conventional long bowl uses dunkers to push the wool sheet into the scouring liquor. The ranks then propel the sheet of wool through the bowl, dislodging the mineral dirt from the fibres in the process. The scratching of fibres against the perforated screen (the false bottom) also helps dirt removal. There is considerable agitation of wool during scouring, which tends to increase the level of wool felting. As mentioned earlier, wool felting is very undesirable, because it leads to increased fibre breakage in the subsequent processes such as carding.

The WRONZ mini-bowl is the most widely used bowl design. The agitation on the wool sheet in the bowl is not as severe as in the conventional long-bowl. In addition, the hopper shaped bowl facilitates fast settling of the dirt in the bottom of the bowl.

The Fleissner suction drum type is the gentlest of the three. Each bowl has several perforated rotating drums half immersed in the scour bath. The scouring liquor inside each drum is pumped into circulation loop and then back to the bowl. When the wool sheet enters the bowl, it is pushed into the liquor by a rotating dunker (not shown in fig. 2.11c) first. The sheet of wool then gets held against the suction drum surface by in-flowing liquor and released as it emerges at liquor surface on the other side. The sheet of wool then flows to the next drum. Since there is little mechanical agitation on the wool, wool felting is minimised during scouring. This is the biggest advantage of the suction drum system. But the reduced agitation also means less dirt removal during scouring. This is the well-known cleanliness-versus-entanglement compromise in wool scouring. Reduced entanglement often means reduced cleanliness as well.

In addition to scouring bowls, the squeeze rollers are also very important cleaning mechanisms. Inadequate roller pressure will lead to scoured wool with a high level of residual grease. Poor opening of the wool before scouring will have a similar effect. Fibre opening and blending before scouring is discussed in the following section.

- **Fibre opening(开毛) and blending(混和) before scouring**

  Most consignments of greasy wool are made up of a number of farm lots or inter-lots. Each lot sold at auction should have a minimum number of 4 bales of greasy wool. On average, each bale weighs about 180 kg. The properties of wool in the different lots are usually quite different. Blending of the greasy wool in different lots is therefore one of the most important functions in the whole topmaking process. The blend should be prepared to ensure a good mix across all the different lots in a given consignment.

As an example, let's assume that we have a consignment of 50 bales of greasy wool, consisting of 4 lots of wool from different farms. It would be very bad practice to feed the lots of wool one after another, because fibre properties differ from lot to lot. One way of mixing the lots and feeding the bales of wool to a scour line is sketched in figure 2.12. Other ways of mixing and feeding the opening process has also been used to minimise the irregularity in the final product.

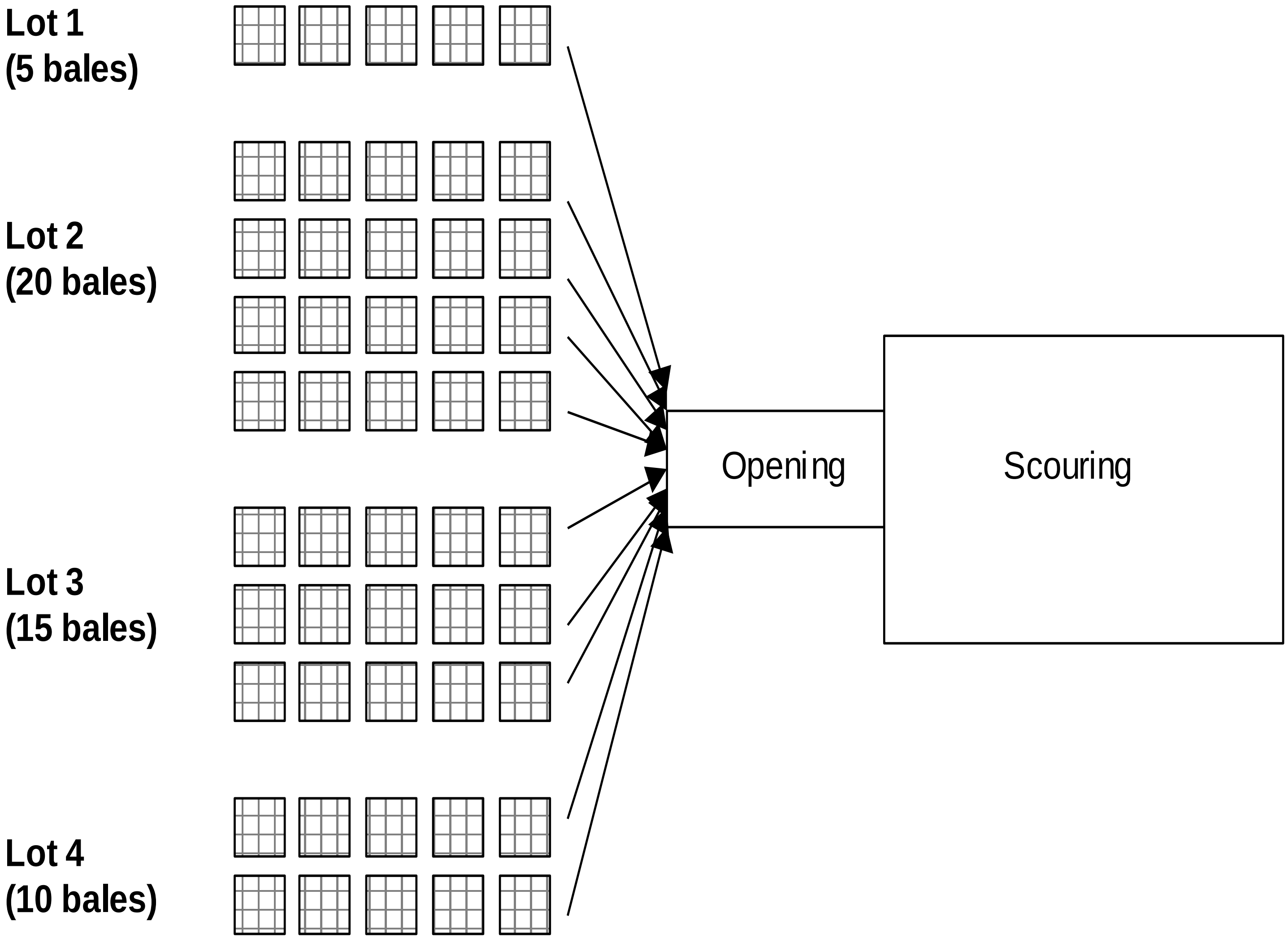


Figure 2.12 Blending of greasy wool bales before scouring

The typical opening systems used are the feed hopper and drum opener, as indicated in figure 2.13.

(a) Feed hopper (b) Double drum opener

Figure 2.13 Pre-scouring fibre opening systems (Stewart 1985, p.5, p.7)

A usual combination of the opening systems is:

Feed Hopper 1 Double Drum Opener Feed Hopper 2 Scouring → → →

With the feed hopper 1, greasy wool from different bales is placed on the feed apron in the hopper, which forwards the wool to the spiked apron. The spikes pick up tufts of wool and move them upwards. Upon meeting the comb drum, large tufts are separated into smaller ones and some small tufts continue with the spiked apron until doffed off by the doffer drum, others are returned by the comb drum to the hopper. The retuned tufts will mix with others already in the hopper, so some blending is also achieved with the feed hopper opening system.

The double drum opener has two toothed drums between which fibres are opened. There are usually perforated screens underneath each drum, which allow dirt and dust to fall away. So apart from fibre opening, some cleaning is also achieved with the double drum opener. Feed hopper 2 will deliver a uniform, opened layer of greasy wool to the scour.

It is worth pointing out that all tri-pack wool (three bales compressed into one for ease of storage and transport) and some farm bales which have had prolonged storage need to be warmed up prior to scouring. Even for ordinary bales, cold climates may warrant bale warming before processing. Warming the bales will loosen and open fibres in the bale, which leads to better scouring and reduced fibre breakage. Bale warming is achieved in a number of ways, the most popular being steam or hot-air heating. A recent development is to heat the bales with the microwave technique.

- **Drying of scoured wool**

The wool leaving the last pair of squeeze rollers has a moisture content of about 40%, or a regain of about 66% ($regain = \frac{mass\ of\ \ water}{mass\ of\ \ dry\ wool}$)It is typical to dry the scoured wool to around 8 to 12% regain.

There are three main types of dryers available for wool - suction drum dryer, conveyer dryer, and Unidryer. They use either gas or steam for heating. Figure 2.14 shows a side view of the three dryers.

Figure 2.14 Side view of wool dryers (Teasdale 1996, p. 97)

1.Suction drum dryer

Upon entering the dryer, the sheet of wet wool is held on rotating perforated drums by suction created by fans on the end of each drum. An internal baffle in each drum blocks half of its circumference so that wool is only held on half of its surface by the suction. As the drums rotate, the sheet of wool is passed from drum to drum so that the heated air passes in alternate directions through the wool for even drying. There is a 'counter-current' airflow inside the dryer. In other words, the direction of air flow is opposite to the direction of wool flow. Fresh (cool) air is fanned in from the delivery end, which cools the dried wool at exit. The air is recirculated to the drums via heating batteries. As the heated air is drawn through the wool, it carries moisture with it to dry the wool. The air is then heated again and drawn through the layer of wool towards the wool inlet, where the wet air is finally exhausted to the atmosphere. Drum dryers usually have between 4 to 8 drums.

2.Conveyer dryer

This is the traditional hot air dryer where the sheet of wool is carried through on a perforated conveyer. Similar to the drum dryer, fresh (ccol) air is introduced at the wool outlet to cool the exiting wool. This air is then heated and blown down through the layer of wool, carrying moisture with in to dry the wool. The now moist air is then heated again and blown through the wool layer towards the wool inlet, where the wet air is finally exhausted to the atmosphere.

Unidryer

This dryer was developed at the University of New South wales. It carries wool between two porous conveyer belts. The conveyer belts pass next to a perforated screen. Again there is a 'counter-current' airflow inside the dryer, with the fresh air coming into the dryer from wool outlet and wet air exhausted at the wool inlet. The direction of airflow in the two chambers is opposite so that wool is dried evenly from both sides. The unidryer is a powerful dryer and is much smaller than the other two.

Worsted Carding

The same adage - "well carded is half spun", as quoted in the cotton carding section also applies to worsted carding. Carding is a vital process in the fibre to yarn processing chain.

- **Objectives**

The main objectives of worsted carding are:

-to disentangle and align the scoured wool,

-to remove the vegetable matters left in the scoured wool,

-to intimately mix the fibres, and,

-to deliver the carded fibres in a continuous rope-like form called a card sliver.

Owing to the scale structure on wool surface, it is unavoidable that some degree of fibre entanglement occurs during aqueous wool scouring. Carding is the only process that can untangle and individualise the fibres. After scouring and drying, the vegetable matters still remain in the wool. The bulk of these foreign matters are removed in carding. Carding also achieves intimate mixing of wool fibres, which is only possible with individualised fibres. Considerable fibre breakage occurs during carding, mainly because of the fibre entanglement. To minimise fibre damage, adequate fibre preparation between wool drying and carding is essential.

- **Fibre preparation before carding**

After the wool is scoured and dried, the moisture content and total fatty matter (TFM) left in the wool are checked. This will allow correct addition of oil/water to facilitate woo carding. Usually the scoured/dried wool is gently opened first by a simple opener as shown in figure 2.15.

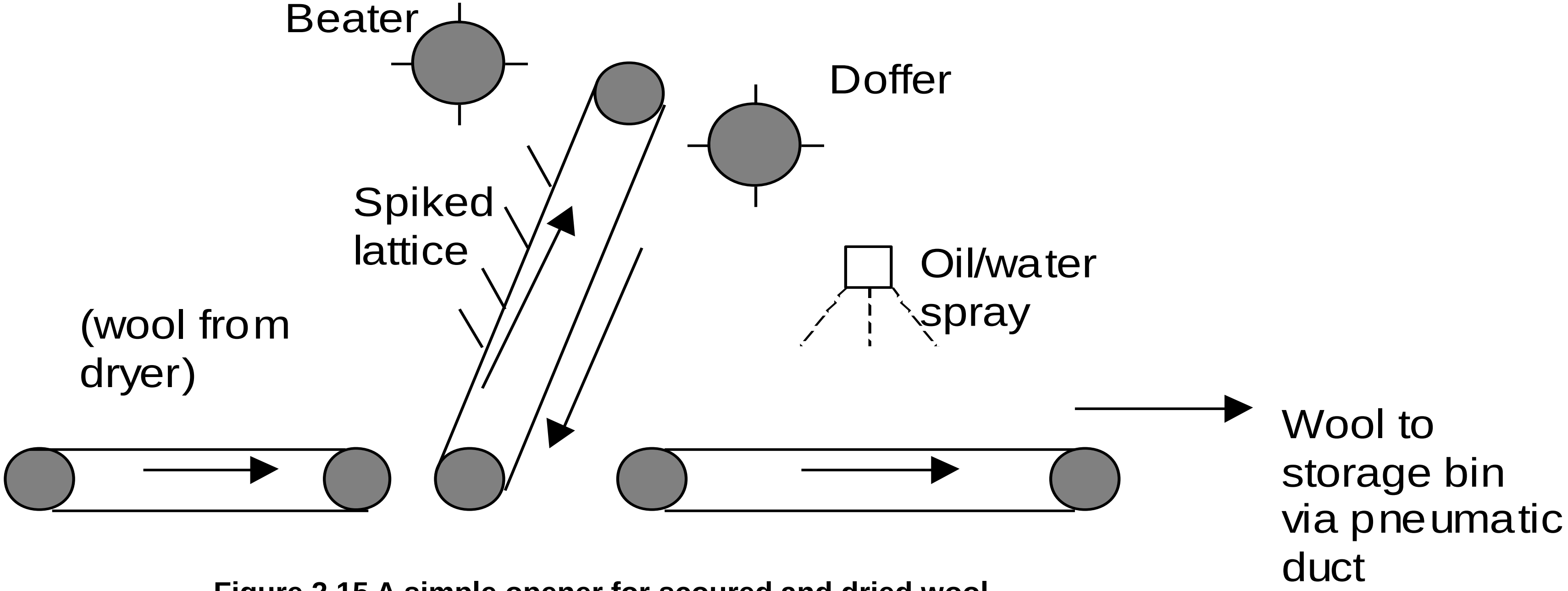


Figure 2.15 A simple opener for scoured and dried wool

A mixture of processing oil and water is sprayed on to the wool, preferably at the delivery end just before the wool enters the pneumatic transport ducts to the storage bins. The wool is allowed to stand for a minimum of 12 hours in the bins to allow oil and water to spread evenly throughout the wool before carding. Insufficient moisture in the wool will cause static problems during carding, while too much oil will cause wool lapping on the card rollers.

- **Roller-top card**

  Unlike the flat-top card used for carding cotton fibres (or other staples of similar length to cotton), a roller-top card is used for carding wool fibres. A simple roller-top card is shown in figure 2.16.

In the simple card depicted in figure 2.16, the broken line represents the flow of fibres. The incoming fibres are first picked up or 'licked in' by the teeth of the lickerin or takerin.

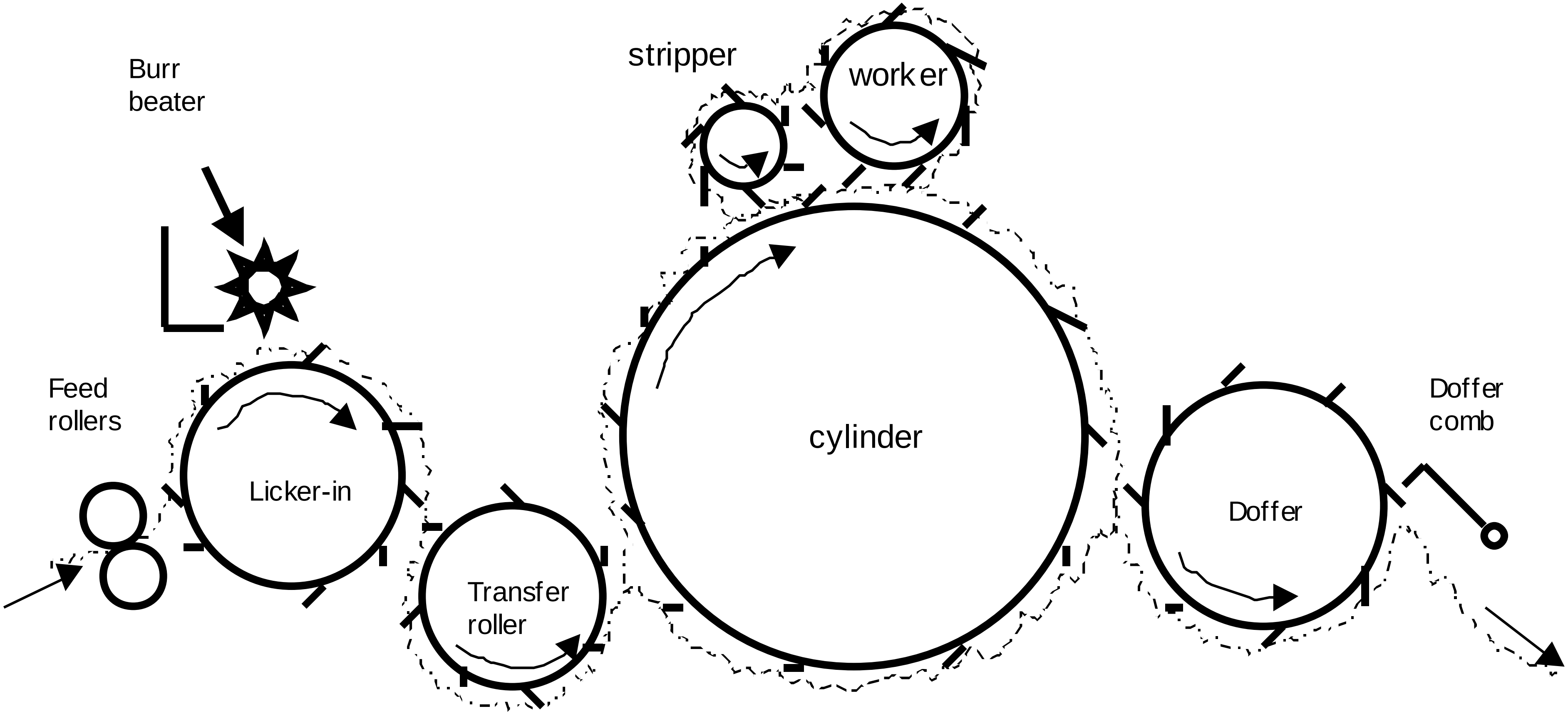


Figure 2.16 A simple roller-top card

As the name implies, a roller-top card has rollers, rather than flats, on top of the cylinder. Roller-top cards are relatively gentle on fibres, which is important in minimising damage to the delicate fibres such as wool. The rollers are clothed with metallic teeth pointing to certain directions. As discussed in cotton carding, the teeth direction, the relative speed between two adjacent roller surfaces, and the rotating direction of the roller surface govern the basic actions (point-to-point carding or point-to-back stripping) between the two adjacent rollers.

In the simple card depicted in figure 2.16, the broken line represents the flow of fibres. The incoming fibres are first picked up or 'licked in' by the teeth of the lickerin or takerin. The sheet of fibres travels with the lickerin and presents the relatively exposed vegetable matters (VM) in the fibres to the flicking action of the beater for removal. Between the lickerin and the transfer roller, a point-to-back stripping action occurs and the sheet of fibres on the lickerin is stripped by the teeth of the trasnfer roller. Another point-to-back stripping action occurs between the cylinder and the transfer roller, which allows the sheet of fibres to be stripped off the transfer roller by the cylinder teeth. The cylinder now carries the sheet of fibres to the very important stripper/worker pair.

The relative surface speed (V) here is: $V_{cylinder} > Vs_{tripper} > V_{worker}$. This, together with the tooth direction and the surface rotating direction as indicated in figure 2.16, gives the following basic actions in the cylinder/worker/stripper unit:

-Cylinder/stripper: point-to-back stripping action; cylinder strips the stripper.

- Cylinder/worker: point-to-point working action; both surfaces will grab some fibres to untangle them.

- Worker/stripper: point-to-back stripping action; stripper strips the worker.

With this arrangement, the fibres carried by the cylinder will 'by-pass' the stripper and proceed to the working (or carding) action of the cylinder/worker pair. This is where much of the fibre untangling and alignment occur in the card. The fibres picked up by the worker will soon meet the stripper and be stripped by the stripper. The stripper then returns these fibres to the cylinder for further action. The fibres that are not picked by the worker will continue their journey with on the cylinder surface, until they reach the doffer. The doffer has a lower surface speed than the cylinder, and a working or carding action happens between them. This would mean that the fibres entering the cylinder/doffer zone is further opened, and a fraction of the fibres will be picked up by the doffer teeth, and this sheet of fibre will then be stripped off the doffer surface by the rapidly oscillating doffer comb.

The fibres not picked up by the doffer will stay on the cylinder surface as 'recycled fibre'. The 'recycled fibres' on the cylinder surface will soon meet with the 'fresh fibres' that have just been picked up by the cylinder from the transfer roller. Together, the recycled and fresh fibres are then presented to the cylinder/worker/stripper unit and the process repeats. The 'looping' of fibres on the cylinder/worker/stripper unit and the recycled fibres meeting with fresh fibres on the cylinder are also important for intimate fibre mixing. From this brief description, we can see that the cyliner/worker/stripper unit achieves the important key objectives of fibre untangling, fibre alignment, and fibre mixing. On a modern worsted card, many such units are employed to ensure sufficient fibre opening, aligning and mixing in carding.

Figure 2.17 shows a schematic diagram of a modern worsted card.

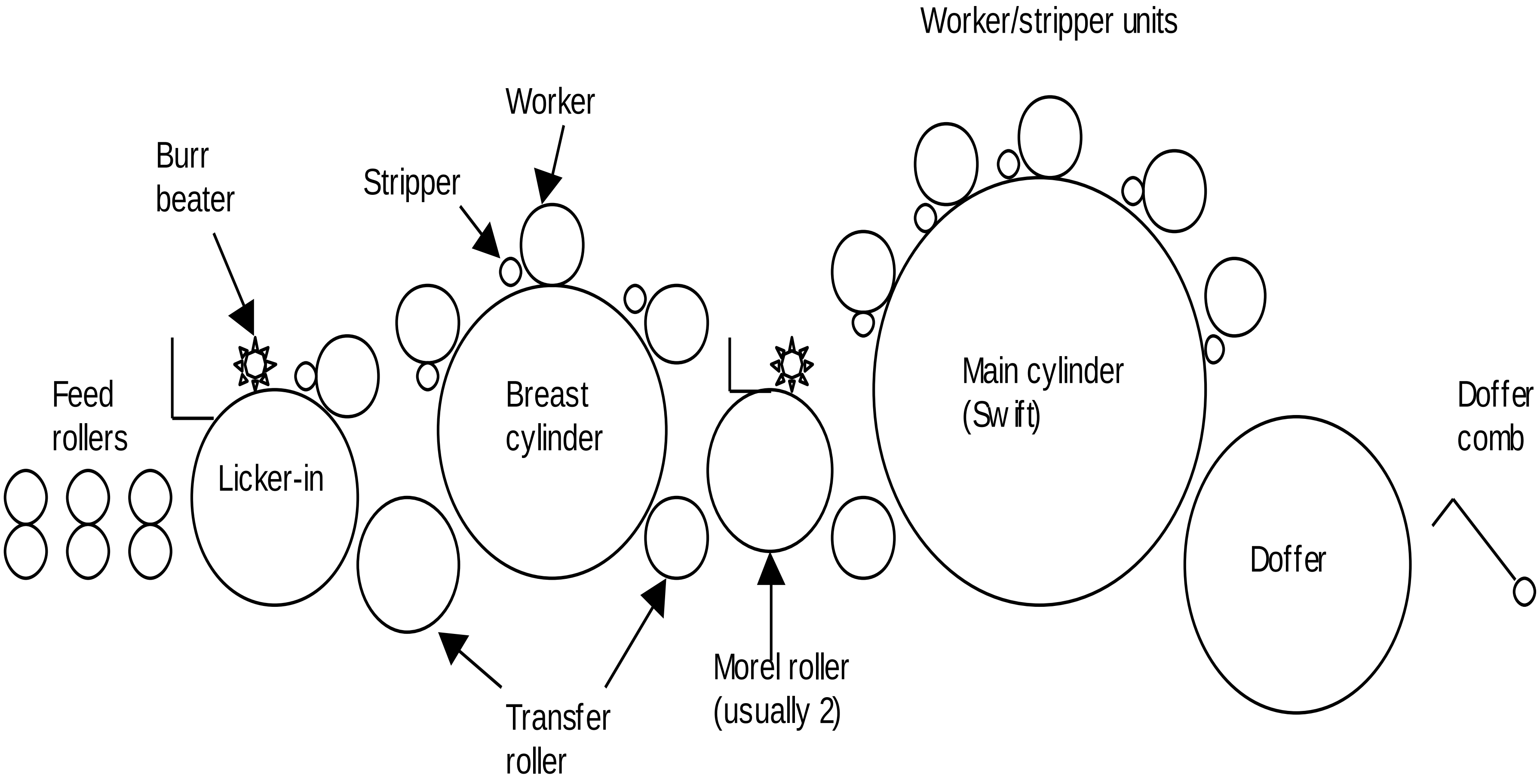


Figure 2.17 **Diagram of worsted roller top card**

A total of nine cylinder/worker/stripper units are employed on the card to achieve the desired level of fibre opening, aligning, and mixing. In addition, the worsted card is often equipped with specially designed burr removal rollers (eg. Morel roller) and burr beaters to free the opened fibres from burrs and other vegetable matters. The morel roller is clothed with special teeth, whose gaps are large enough to accommodate the fibres but are too small for the vegetable matter, so that the vegetable matter can be beaten off by the bur beaters on top of the morel roller. The thin web of fibres removed from the doffer by the doffer comb is usually condensed into a sliver or rope form, and deposited into a sliver can or coiler can for further processing. Figure 2.17a shows a sketch of a sliver can with coils of sliver inside.

- **Important settings in carding**

(1)Card loading or production rate

The theoretical production rate of a worsted card can be calculated using the formula below:

$$Theoretical\ production\ rate(kg/h) = \frac{2.9 \times MFD\,(micron) \times Card\ width\,(m) \times Swift\ speed\,(m/\mathrm{min})}{1{,}000}$$

This is the production rate at 100% efficiency, and is related to the mean fibre diameter (MFD), card width, and the swift surface speed.

If the card is in good condition and set properly, it can produce quality products at this theoretical production rate. Otherwise a lower rate is necessary to reduce fibre breakage during carding. The usual way of checking card performance is to process the card slivers to tops, and examine the length characteristics of the tops on the Almeter and calculate the coming yield and noil figures.

(2)Fresh fibre density (FFD)

Research at CSIRO has demonstrated that the density of fresh fibres on the main cylinder (swift) has a major effect on fibre breakage in the carding process. The fresh fibre density (FFD) is calculated using the formula below:

$$Fresh\,Fibre\,Densty(g/m^2) = \frac{\mathrm{Pr}oduction rate(kg/h) \times 1{,}000}{60 \times Swift\,speed(m/\min) \times card\,width(m)}$$

By combining this equation with the formula for production rate, we can derive the formula for theoretical fresh fibre density (FFDt):

$$Theoretical\ fresh\,fibre density(g/m^2) = \frac{2.9 \times MFD\,(micron)}{60}$$

If the actual fresh fibre density is significantly higher than the theoretical fresh fibre density, considerable fibre breakage may arise during carding. On the other hand, if the actual fresh fibre density is kept below its theoretical value, increasing the card production rate will have little effect on the quality of the carded sliver. It is worth reiterating that the only way to confirm card performance is to check the fibre length characteristics on the Almeter and calculate combing yield and noil figures at each different setting.

(3)Roller settings

The clearance between adjacent roller surfaces and the relative surface speeds are important settings that affect carding quality. The clearances gradually decreases from the feed to delivery end of the card as the fibre materials become thinner. The card manufacturer will advise on the best settings for the particular type of fibre being processed by its card. Incorrect settings may reduce the mean fibre length, and increase the number of neps in the carded sliver.

The reading material "The pressure on fibres in carding" by Harrowfield, Eley and Robinson (1986), reports relevant research carried out at CSIRO.

Like the cotton card, a properly set worsted card also generates a majority of trailing fibre hooks in the carded sliver, which are then straightened in the gilling (drawing) processes following carding. Despite of the best effort, fibre breakage and other less dramatic forms of fibre damage are unavoidable in carding. Poor scouring leading to increased fibre entanglement, excessive fresh fibre density, and poor lubrication are the main causes of fibre breakage in carding. In addition, highly entangled balls of fibres (called neps) are also generated in carding. Card surfaces with blunt teeth may lead to rolling of fibres between adjacent surfaces and create neps in the process. Grinding of card clothing to maintain sharpness of the teeth will reduce this problem. Another possible mechanism of nep formation in carding is the 'snap back' effect. In carding, many fibres are stretched at high extension rates. When one fibre breaks, the broken end may 'snap back' and entangle with neighbouring fibres to form neps. Most of the broken short fibres plus the neps generated in carding are subsequently removed as waste fibres (noils) in the combing process. This is also why the combing yield and noil can reflect the performance of carding.

Preparatory Gillings(预针梳)

- **Objectives**

The main objectives of the gilling machine are to further align the fibres in card sliver and to blend the slivers from different cards.

A gilling machine is also known as a gillbox, or simply a gill.

As discussed before, most fibres in the card slivers have hooked ends, with the trailing hooks at a majority. These hooks and other poorly aligned fibres should be straightened out before combing to increase the average fibre length and reduce the percentage of noil during combing.

- **Gilling process**

Gilling is basically a roller drafting process in which fibre movements are controlled by pins fixed on moving pinned bars (faller bars). Figure 2.18 shows a schematic of a gillbox with intersecting upper and lower faller bars controlling fibre movement during drafting. Such a gillbox is also called an intersecting gillbox.

Figure 2.18 Schematic of an intersecting gillbox (Grosberg and Iype 1999, p.14)

You may recall that perfect roller drafting requires fibres in the drafting zone travel at the speed of back rollers until their leading ends reach the front roller nip, where they get accelerated to the front roller speed instantly. In gilling, several slivers (eg. from different cards) are combined as the input material, which is drafted to produce a single sliver at the output. During drafting, the faller bars move at about the same speed as the back rollers and the pins on the faller bars keep the fibres moving at a similar speed. Once the leading end of a fibre gets gripped by the nip of the front rollers, that fibre gets pulled through the pins on the faller bars and has its trailing end straightened. So each passage of gilling straightens fibre trailing ends mainly.

The distance between the front roller nip and the closest faller bar is called the front ratch setting. This setting is very important for gilling. If it is set too large, then many fibres in the critical region near the front rollers are not properly controlled by the pinned faller bars during drafting. We already know that lack of fibre control during drafting will lead to increased irregularity in the drafted material. On the other hand, if the front ratch setting is too small, pulling the fibres through the pins on the faller bars may cause fibre breakage. In practice, the front ratch setting is set at about half of the average fibre length. Using this value as a starting point, the final setting should be optimised based on sliver evenness results, particularly the spectrograms obtained from the Uster evenness tester. As discussed in the Module on Yarn Evenness, the spectrograms allow us to identify the presence of drafting faults such as drafting waves. If a drafting wave is identified from the spectrogram, a closer front ratch setting should be used to improve fibre control and reduce the number of floating fibres during gilling.

- **Three intermediate gillings**

  It is common practice in the worsted industry to have three intermediate gillings between carding and combing. You may ask why this is necessary. To answer this question, we need to keep in mind the following three points:

(1) Fibres in card slivers have a majority of trailing hooks

(2) There is a natural reversal of fibre ends between two processing stages ('first-in-last-out')

(3) In feeding a worsted comb, fibres with leading hooks tend to cause more fibre breakage in combing (note the difference between worsted combing and cotton combing!)

Figure 2.19 shows the configuration of fibre hooks during gilling.

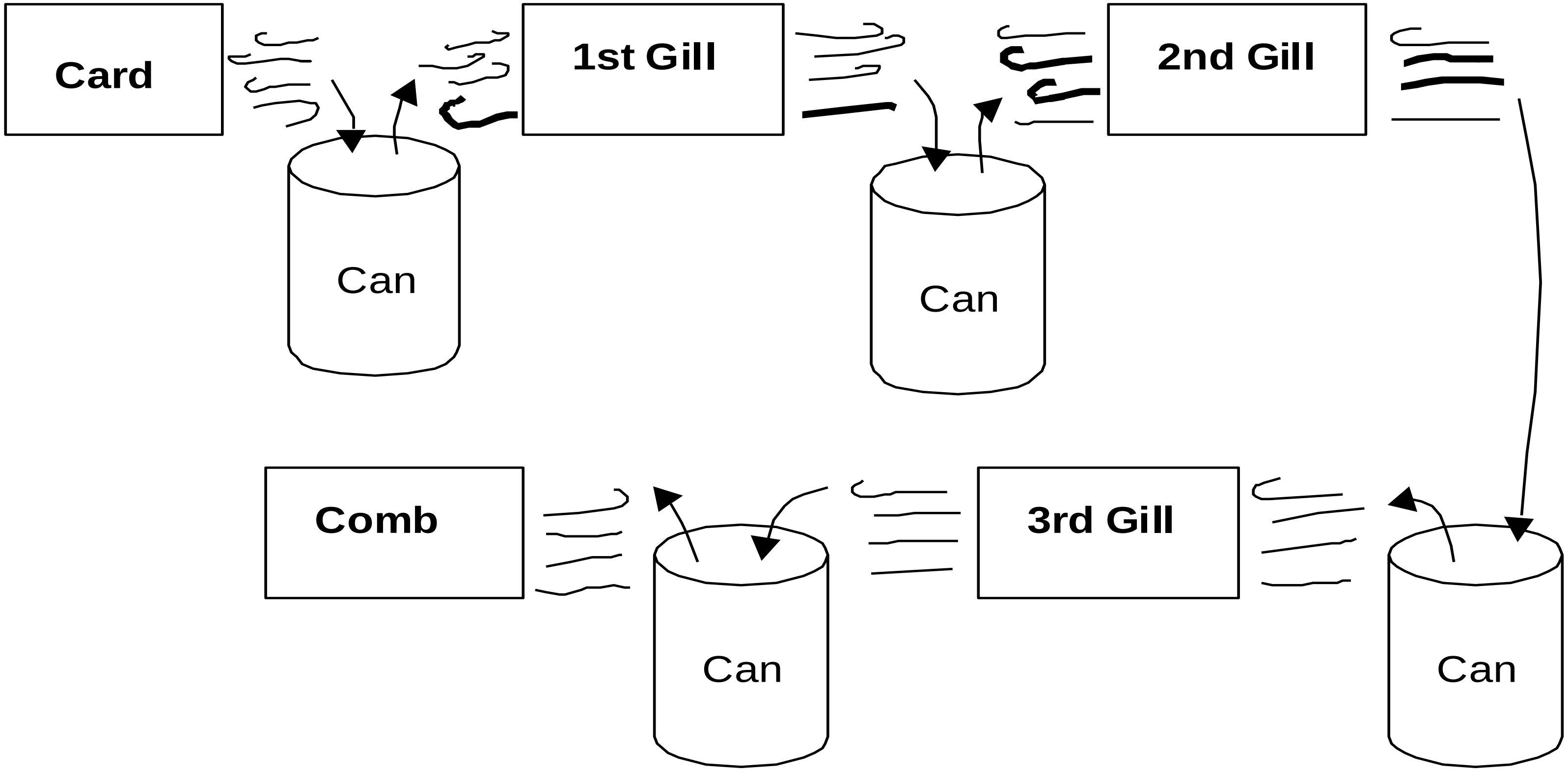


Figure 2.19 Fibre configurations from card to comb

The card produces fibres with a majority of trailing hooks. When the card sliver is deposited into a can and then taken out to feed the 1st gill, there is a reversal of fibre ends, so that the fibres entering the 1st gill have a majority of leading hooks. Because gilling straightens trailing hooks only, the fibres will emerge from the 1st gill still with the leading hooks. Now the 1st gilled sliver is stored in a can and taken out again for the 2nd gilling operation. The reversal of fibre ends mean that fibre entering the 2nd gill have a majority of trailing hooks, most of which are straightened during this 2nd gilling. So after the 2nd gilling, most fibres are straight except for a few which may still have some trailing hooks. After a further can storage and removal from the can, the sliver now enters the 3rd gill with a few fibres with leading hooks, which can not be straightened and will persist to the 3rd gilled sliver. But when the 3rd gilling sliver is stored in a can and taken out for combing, any remaining hooks in the sliver would be trailing, which is fine as far as worsted combing is concerned. Feeding a worsted comb with leading hooks is likely to increase fibre breakage during combing, as will be discussed in the following section.

From figure 2.19, you may think that the 3rd gill has done nothing to the fibres. This is not quite true. In gilling as in cotton drawing, there is a doubling function as well. Many slivers are fed to a gill together, and there is a doubling and blending function by each gill, which improves the evenness of the gilled sliver.

Five intermediate gillings between worsted carding and combing have been tried before, but the benefit is too marginal to justify the cost for two extra gillings.

After the 3rd gilling, the slivers are ready for combing. Combing is discussed next.

Worsted Combing(精梳)

- **Objectives**

Combing is a critical step in worsted processing. Similar to cotton combing, worsted combing achieves the objectives of:

(a) removing short fibres, neps, and impurities
  (collectively known as noils)
(b) further mixing and aligning fibres
(c) forming a continuous rope-like comb sliver

Since longer and cleaner wool fibres make better yarns, combing improves the yarn quality and combed yarns command a high price.

- **Combing process**

A schematic diagram of a rectilinear worsted comb is shown in figure 2.20. Up to 32 carded and gilled slivers may be fed to the comb via a pair of feed rollers and the feed gill assembly. Like the cotton comb, worsted comb also runs in an intermittent fashion. In each cycle, the following actions are performed:

(1) Feeding a short distance of slivers to the comb
(2) Initial combing of fibre leading ends by the cylinder comb or comb cylinder
(3) Final combing of fibre trailing ends by the intersector comb or top comb
(4) Detaching the fully combed tuft and overlapping it with previously combed ones

Figure 2.20 A side elevation of a worsted comb (Brearley 1964, p50).

During the initial combing stage, the fibres are firmly gripped by the nips or nipper jaws. Fibre leading ends protruding from the nipper jaws are combed by the comb cylinder (also known as the circular comb). Fibre penetration of the pins is aided by a nipper brush (not shown in figure 2.20) attached to the upper nipper. In the initial combing process, short fibres, neps and impurities are removed as noils by the comb cylinder, which itself is then cleaned by the noil brush. If some fibres have large leading hooks, there is a possibility for the leading hooks to be engaged by the teeth on the comb cylinder and fibre breakage will occur as a result. This is why it is preferable that no leading hooks exist in the feed stock. In contrast, the presence of leading hooks in the feed stock to cotton combs is normal, since there are only two passages of drawing between cotton carding and combing. The difference is that for short staple fibres such as cotton, the fibre length is much shorter than long staples such as wool. Even if there are leading hooks, the extent of the hooks will be considerably smaller and the small hooks are unlikely to be engaged by the teeth of the comb cylinder to cause fibre breakage.

In the final combing by the intersector comb (also known as the top comb), the trailing ends not combed by the comb cylinder are combed. The short fibres, neps and impurities are held back by the intersector comb, and will be removed in the next combing cycle. The noils or combing noils (i.e. short fibres, neps and impurities) represent combing waste. The value of noils is about one third of that of tops, so any increase in the percentage of noil is going to cost the topmaker large sum of money. But an increase in noil is usually accompanied with an increase in the mean fibre length of the combed sliver, because more short fibres are removed. This improves the value of the tops. So choosing the right percentage noil is a balancing act. A 6% noil is typical in modern topmaking mills.

Each fully combed tuft of fibres is drawn off by the drawing-off rollers and laid on top of the previously combed ones, like shingles on the roof. This overlapped web of fully combed fibres is then consolidated by the calender rollers and deposited in the sliver can. Because fibres in the combed sliver simply overlap, the cohesion between fibres is very small, therefore the combed sliver is very weak. To improve the strength of combed slivers, the slivers may be crimped by a crimping mechanism before they are deposited into the coiler can.

Figure 2.21 shows the worsted combing in separate stages, noting that the upper nipper has a brush attached to it to assist with fibre penetration into the pins of the circular comb.

Figure 2.21 A graphical representation of worsted combing process (CSIRO Wool Textile News, Feb. 1969).

- **Settings on the comb(精梳机工艺参数)**

(1)Noil**(落毛)** setting

Noil setting is also known as detachment setting or gauge setting. It is the closest distance between the bite of the nippers and the nip line of the detaching rollers. On a worsted comb, this setting may vary from 26 mm to 40 mm. A large ratch setting will lead to increased noil, and longer mean fibre length in the top. This will be further discussed in the following section on the geometrical model of worsted combing.

(2)Feed**(喂入)**

Normally about 12 to 32 slivers are fed to a worsted comb, depending on sliver weight and machine design. A practical rule of thumb is:

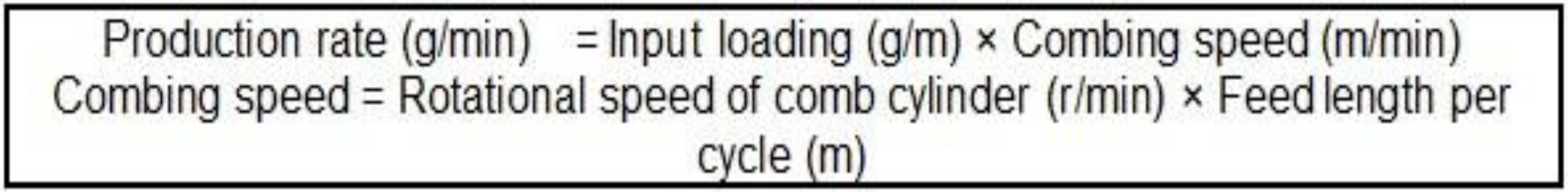
Rule of thumb for feed: Input ktex = 20 x Micron

For example, if the comb is processing 22 micron wool, then the total density of the feed stock may be set at 20 x 22 = 440 ktex.

As mentioned earlier, the comb operates in an intermittent fashion. On a worsted comb, the feed length is usually adjustable between 4.5 to 9 mm per combing cycle.

(3)Production rate(产量)

The comb production rate can be calculated using the formulas below:



Production rate (g/min) = Input loading (g/m) × Combing speed (m/min)

Combing speed = Rotational speed of comb cylinder (r/min) × Feed length per cycle (m)

A practical rule of thumb is:

Rule of thumb for production rate:

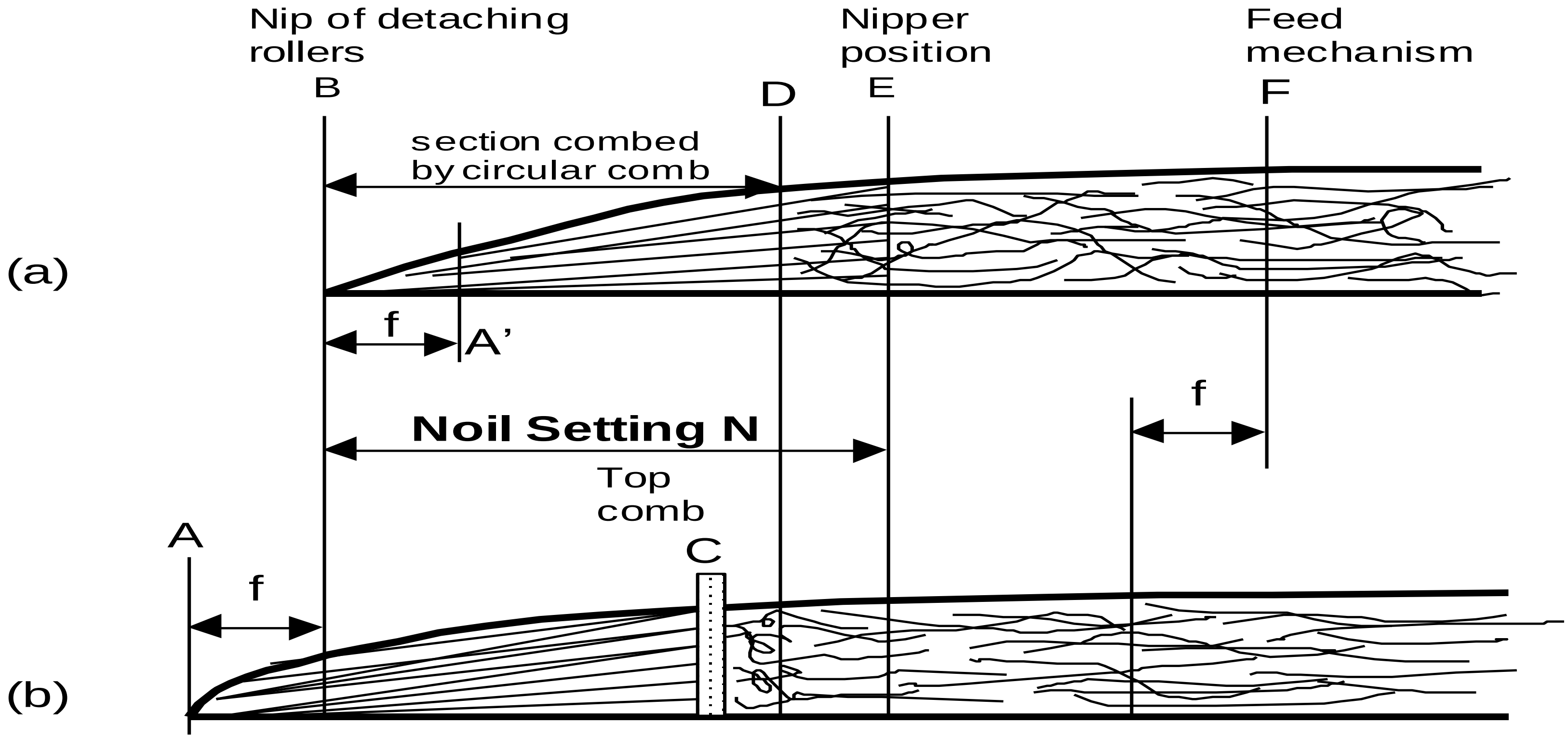
Prod.Rate = 1.4 x Micron

It is typical for a worsted comb to have a production rate between 20 to 40 kg/hour.

Geometrical theory of worsted combing

- **Geometrical theory of worsted combing**

Belin and Walls (1963) developed a geometrical model of fibre selection in worsted combing. This model is represented in figure 2.22 below.



(a) Fibre beard in the combing zone BD combed by circular comb and about to be presented to the detachingrollers. DE is the 'dead zone' in front of the nipper, where pins on the comb cylinder can not reach
(b) Fibre beard advanced a distance 'f' by the feed mechanism F. Fibres with ends inside detaching zone AB removed to combed sliver, their tail ends combed by the top comb C

Figure 2.22 Geometrical model of fibre selection in worsted combing

This model shows that for fibres not held by the nippers, the combing action of the circular comb will remove them as noils. These are the relatively short fibres, i.e. fibres shorter than the noil setting (N). Longer but poorly aligned fibres not gripped by the nippers will also be removed as noil. After the initial combing by the circular comb, the fibre beard is fed forward a short distance represented by 'f' in figure 2.22. Combed fibres with leading ends reaching the detaching zone A'B (AB after feeding) will be pulled through the top comb by the detaching rollers and they will end up in the combed sliver. If a fibre has its trailing end just gripped by the nippers and its leading end just reaching the detaching zone A'B, this fibre will end up in the combed sliver, even though its length is relatively short (slightly longer than N - f). On the other hand, if a relatively long fibre of length N is not gripped by the nippers, it will end up as noil regardless of the fact that its leading end is well inside the detaching zone A'B. Therefore, it is inevitable that a few fibres in the noil are longer than some fibres in the combed sliver. This will be more so if the fibres are not well aligned before combing. This also highlights the importance of pre-comb gillings and the necessity to straighten fibres before combing.

For any fibre that is shorter than (N - f), there is no way that this fibre will be able to get gripped by the nipper and in the same time having its leading end inside the detaching zone A'B, so this fibre will always end up in the noil.

During detaching, the top comb is inserted just a short distance in front of the 'dead zone' DE to ensure that fibres are fully combed along their entire lengths. The 'dead zone' exists because the pins on the circular comb can not reach right up to the nipping points of the nippers. In practice, this 'dead zone' length is reduced with the aid of a nipper brush, which pushes the fibres into the pins on the circular comb (figure 2.21). The impurities, short fibres and neps blocked by the top comb during detaching are removed as noil in the next combing cycle.

- **Effect of combing on fibre properties**

In addition to the obvious changes in fibre length, combing also changes fibre diameter slightly. With wool fibres, finer fibres are usually shorter ones, and are also easier to break during carding and combing. Since combing removes short fibres mainly, the average diameter of fibres in the noil is about 10% finer than the raw wool from which they have been produced. With the removal of relatively shorter and finer wools, the combed sliver has an average fibre diameter that is about 1% coarser than the raw wool from which the combed sliver is produced. In absolute terms, it is usual for the average fibre diameter to increase by about 0.3 micron after combing. This increase should be considered when selecting raw wool, as discussed in the section on TEAM formulae and applications.

The reading material "ITMA'99 - long staple gilling and combing" by Atkinson (1999) discusses the latest developments in worsted gilling and combing, as exhibited at the 1999 international textile machinery exhibition.

Worsted Top(精梳毛条) Finishing

The worsted top finishing usually consists of two gilling operations on the combed slivers.

- **Objectives**

The objectives of top finishing are:

-Randomise comb overlap effect

-Mixing of fibres from different combs

-Producing tops of the right count, regain, and package form

-Improving the evenness

An explanation of some of these objectives is given in the following section.

- **The process**

As with gilling before combing, the top finishing gilling processes combine drafting, doubling and pin control.

As the combed slivers are removed from the storage cans to feed the 1st finishing gillbox, they follow the 'first-in-last-out' order (i.e. natural reversal of fibre ends). Because of this natural reversal, fibres in slivers fed to the 1st finishing gilling are drafted in the reverse direction, i.e. opposite to the direction of fibres as they came out of the comb. This is known as 'reverse drafting'. The reverse drafting helps to randomise the overlapping fibre ends in the combed slivers, leading to improved sliver strength due to the increased inter-fibre cohesion. This is shown in figure 2.23.

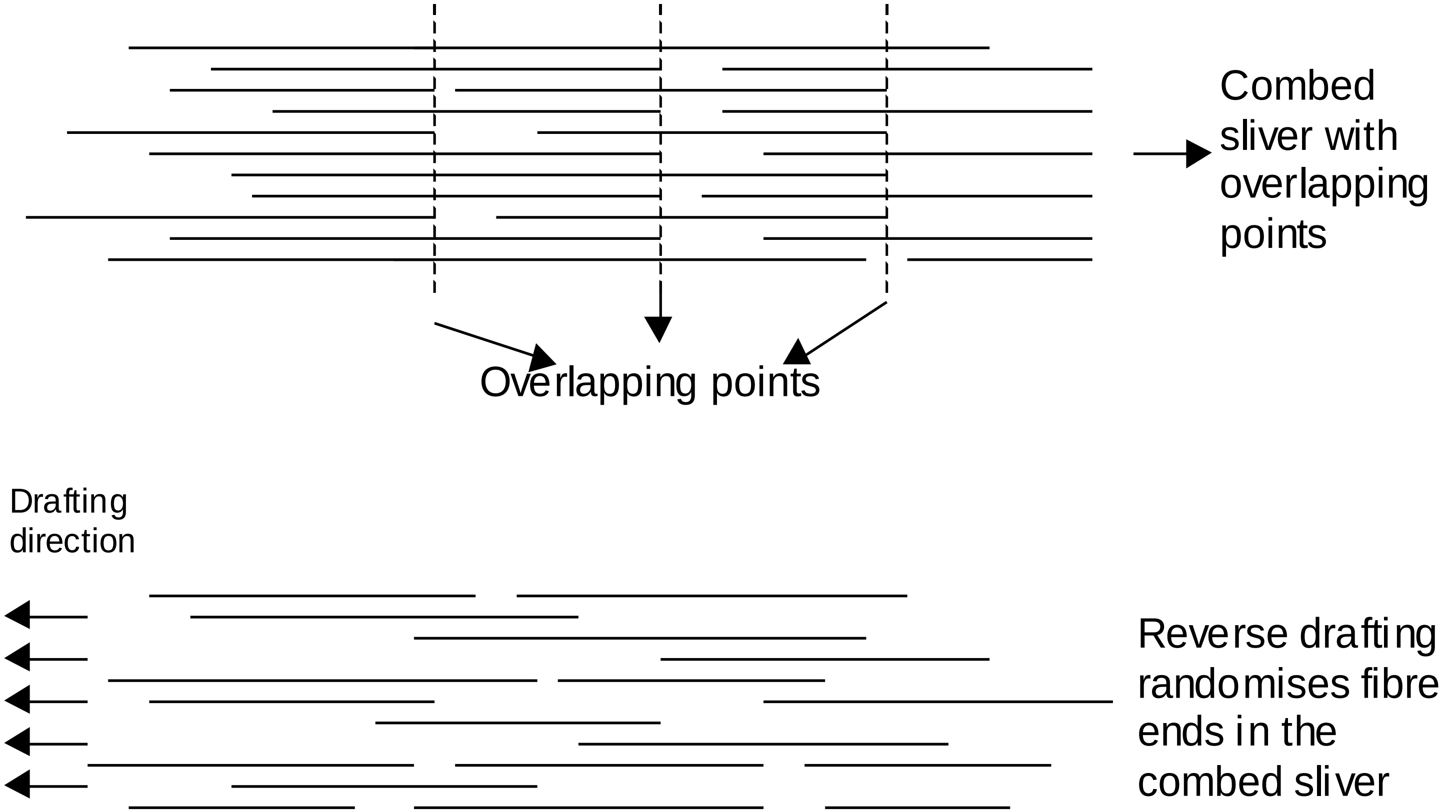


Figure 2.23 Reverse drafting randomising comb overlapping effect

The first finishing gillbox feeds on slivers from many combs. This doubling of slivers (from different combs) in the gilling process improves the evenness of the gilled sliver, as discussed in the module on yarn evenness. A special control mechanism is often used in the finishing gill to automatically level or regulate the sliver evenness, such a mechanism is called an autoleveller.

- The principle of autolevelling has been discussed in the first topic of this module. Figure 2.24 shows a gillbox with an autolevelling system. The slivers are fed into the gillbox via a condenser funnel and a pair of measuring rollers. This measuring rollers are known as tongue and groove or shoe and groove rollers. The bottom roller has a groove through which the slivers run. The tongue or shoe roller is the top one, which sits in the groove roller, pressing on the slivers. Variations in the amount of fibre materials running through the tongue and groove rollers will cause the tongue roller to move up or down. This movement reflects the variation in material thickness and is automatically recorded as a 'pattern line' on the memory unit. The memory unit then feeds this information forward to the transmitter unit, which controls a variable speed mechanism. This mechanism can change the speed of the back rollers to vary the draft. For example, if the tongue and groove measuring unit detects a thick section running through, this information is recorded and fed forward to the transmitter. When the thick section arrives in the drafting zone, the variable speed mechanism will reduce the back roller speed to increase the draft on this thick section. Conversely, if the measuring unit detects a thin spot section coming through, the draft on the thin section will be reduced by increasing the speed of the back rollers.
- Figure 2.24 Autolevelling gillbox (Brearley and Iredale 1980, p.83)

After two finishing gillings, we get worsted 'tops'. The tops are usually packaged in balls or in bumps. Balls are self-supporting cross wound tops, while bumps are press-packed layers of coiled tops.

The tops should be of the right moisture content. The standard regain for tops is about 18%. It is normal to spray moisture on the sliver at the delivery end of the first finishing gill, to bring the regain up to about 19% first. At the 2nd finishing gilling process, about 1% of the moisture is lost through evaporation.

- **Quality of wool tops**

  From a spinner's point of view, tops should be produced to the spinner's specifications. These specifications usually include requirements on the following:

  -Fibre diameter (micron) and CV of fibre diameter

  -Average fibre length (Hauteur) and CV of Hauteur

  -Count or size of the top

  -Short fibre content

In addition, the tops should be free from contaminations (coloured fibre, vegetable matters, bale packing materials etc), and of the correct shape and density.

The TEAM equations discussed before have been routinely used by top-makers to select the right wool for the tops, and for predicting the important quality attributes of tops according to raw wool specifications.

Worsted Drawing

- **Objectives**

  After the tops arrive at a worsted spinning mill (or the spinning department of a vertical worsted mill), they go through a series of drawing processes. The main objectives of worsted drawing are:

-Reduce the count of tops gradually before spinning

-Mix tops of different properties

-Minimise irregularity in count, colour etc.

- **Drawing process**

The drawing sequence differs from mill to mill. A typical sequence of producing a 21 tex worsted yarn is given in Table 2.5

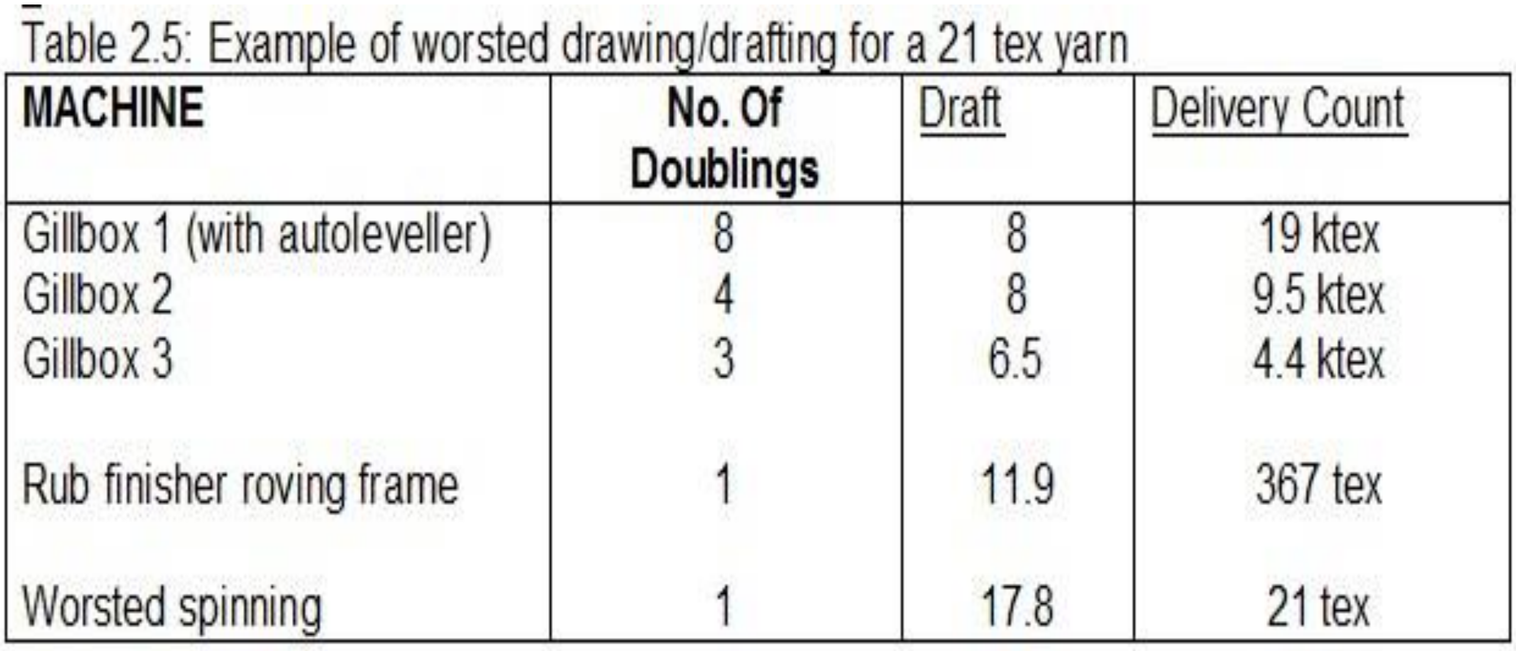


Table 2.5: Example of worsted drawing/drafting for a 21 tex yarn

MACHINE	**No. Of Doublings**	Draft	Delivery Count
Gillbox 1 (with autoleveller)	8	8	19 ktex
Gillbox 2	4	8	9.5 ktex
Gillbox 3	3	6.5	4.4 ktex
Rub finisher roving frame	1	11.9	367 tex
Worsted spinning	1	17.8	21 tex

The roving frame used in the worsted system is mainly of the rub finisher type, although a flyer roving frame is also used. A schematic of the rub finisher roving frame is shown in Figure 2.25.

Fig. 2.25: Schematic of a rub finisher roving frame (Grosberg and Iype 1999, p.16)

The rub finisher roving frame uses roller drafting to attenuate the input sliver. The roving straight after drafting is weak, since no twist is inserted into the roving. To increase the strength of the roving, rubbing aprons are used to consolidate the roving to increase fibre cohesion. Each roving package normally has two rovings wound up side by side without being twisted together (parallel winding). The rovings are then used to feed a worsted ring spinning machine.

Because the roving stage is the last process before spinning, it is important that rovings are of good quality. The Uster spectrograms are often used to check whether there is any periodic mass variation in the roving. If there is, it should be rectified as soon as possible before further processing.

Once we have the rovings, spinning can commence to make yarns. Spinning is discussed in the next module.

While we have devoted this topic to worsted processing, it is also important to know the system of woollen processing. The reading material “Woollen processing system” by Osborne (1998) provides essential information on the differences between worsted and woollen processing.

Review questions

(1) If a 20 tex weaving yarn is to be produced with an average number of 40 fibres in yarn cross section. What would be the right average diameter of the raw wool for the top-making process? You need to show the calculations involved and consider changes in fibre diameter during top-making.

(2) In your own words and use sketches if necessary, explain how detergent helps to remove grease from the surface of wool during the aqueous wool scouring.

(3) An important unit on a card is the cylinder/worker/stripper unit. Explain, with the help of sketches, how this unit helps achieve the objectives of fibre opening, aligning, and mixing during carding.

(4) With reference to carding, gilling and combing processes, explain why three intermediate gillings are commonly used in worsted top-making.

(5) With reference to the geometrical model of fibre selection in worsted combing, explain:

(a) Why is possible to find a few fibres in the noil that are actually longer than some fibres in the combed sliver?

(b) What happens to the noil% and the mean fibre length of the combed sliver is the feed 'f' is increased?