15. Principles of Wool Fabric Finishing

Mike Pailthorpe and Errol Wood

Learning objectives

On completion of this topic you should be able to:

- Explain the various types of dimensions change that can occur in fabrics
- Describe the finishing methods used to remove contaminants from greige state wool fabrics
- Outline the finishing methods used to stabilise the dimensions of wool fabrics
- Describe the methods used for drying wool fabrics
- Describe the finishing processes employed to modify the handle and appearance of wool fabrics

Key terms and concepts

Inspection, burling, mending, scouring, crabbing, carbonizing, milling, shrink proofing, bleaching, hydroextraction, scutching, drying, conditioning, raising, shearing, singeing, pressing, decatizing, perching.

Introduction to the topic

The objective of wool fabric finishing is to develop the desired properties in woollen and worsted fabrics that meet the specified end use requirements of consumers. Finishing is a sequence of dry and wet processes that is carried out in a logical order. There are four main objectives to be achieved from the finishing of wool fabrics.

- The removal, by scouring, of contaminants from the fabric. These contaminants may include lubricants and antistatic agents employed in yarn and fabric production, warp sizes and lubricants, machine oil stains, etc. In some cases the wool fabric may also contain vegetable matter (VM), in which case the process known as carbonising may be used to remove the VM
- The development of the required handle, softness, fullness, drape, etc.
- The control of the dimensional stability of the fabric, e.g. relaxation shrinkage, felting shrinkage, and hygral expansion
- The application of functional finishes, e.g. antistatic agents, flame-retardants, water-proofing agents, soil repellents, etc.

This lecture provides an overview of the principles of wool fabric finishing. The topic of wool fabric finishing is a very extensive one, and therefore can only be dealt with quite briefly here. While fabric dyeing can be regarded as a finishing process, this is discussed in Topic 13.

The general references for this topic are Rouette and Kitten (1991), Levene (1984), Brady (1997), De Boos (2003), Shaw and White (1984), Miles (2003) and Connell (2003). The Rouette and Kitten reference is a comprehensive book on the subject of wool fabric finishing.

15.1 Overview

Woven and knitted fabrics, taken straight from the loom or knitting machine, are known as greige (or grey) state fabrics. Such fabrics must be finished using wet and dry processes to produce high quality fabrics that are suitable for their intended use, e.g. suitings, knitwear, furnishing fabrics, etc.

Wet finishing

The objectives of wet finishing of wool fabrics are firstly to remove contaminants from the wool by scouring and, if necessary, by carbonising. The latent stresses and strains the fabrics must then be relaxed, and the fabric set, in a process known as crabbing. Special qualities can then be developed in the wool fabrics by processes known as milling, shrink proofing, bleaching and dyeing. These so called wet finishing processes are grouped together, the aim being to minimise water consumption and to dry the fabric only once.

The so called dry finishing processes for wool fabrics follow on after hydroextraction and scutching, beginning with drying. One of the objectives in wool fabric finishing is to dry the fabric only once, to minimise energy usage.

Removal of contaminants

Greige-state fabrics (direct from the loom or knitting machine) are likely to contain contaminants that must be removed by a scouring (washing) process. These contaminants may include residual wool grease that was deliberately left on the wool after raw wool scouring, processing assistants (spinning lubricants, warp sizes, warp lubricants, antistatic agents, etc), adventitious soiling (machine oils, factory dust, lint, etc) and unfixed dyestuffs (from stock or yarn dyeing processes). If a greige-state fabric contains vegetable matter (VM), then it may be necessary to carbonize the fabric to destroy and remove the VM.

Improvement of dimensional stability

Greige-state wool fabrics have very poor dimensional stability, and great care must be taken in handling wool fabrics through the sequence of wet finishing processes. Depending upon fabric type, it may be necessary to stabilise the dimensions of the fabric before the scouring process, using a process known as crabbing. The decision to scour first, or crab first, is based upon the experience of the finisher. One of the risks in crabbing first is that one might set any stains in the wool fabric, making removal of the stains in subsequent scouring more difficult. Additional dimensional stability, together with lustre and handle, are achieved later in the finishing sequence by a process know as decatizing.

Shrink-resist processes

Wool fibres, like all animal fibres, have surface scales that give rise to the so called differential frictional effect (DFE). DFE, in combination with other fibre properties, can lead to felting shrinkage in wool fabrics. Finishers can make use of this property in a process known as milling (or fulling) to achieve consolidation of the fabric, increased fabric weight, reduced air permeability, etc. On the other hand, felting shrinkage can be detrimental to the performance of wool fabrics and the finisher must shrink-resist the fabrics. Shrink-resist processes may be degradative or additive. Degradative processes use chemicals, e.g. sodium hypochlorite, to chemically etch away the scales and hence reduce the DFE. Additive processes use polymers to either mask the scales or spot-weld the individual wool fibres together.

Whilst dyeing is not normally considered to be a part of the finishing process; dyeing can have a great influence on fabric quality. Wool fabric dyeing can be carried out in rope form or in open width form. Dyeing in rope form can lead to a degree of milling (consolidation) and may even completely change the character of the fabric. On the other hand, dyeing in open width may lead to flat setting of the fabric.

Dry treatments

Once all the wet finishing processes have been completed, the fabric is dried. The first step in the drying sequence is the removal of liquid water from the fabric by mechanical means; usually by mangling or centrifuging. The second step is the removal of the remaining water using heat energy, usually in a stenter (or tenter). The stenter controls the dimensions of the fabric during drying by holding the selvedges of the fabric with tenter hooks or clamps.

After drying, a sequence of dry finishing processes is used to develop the fabric characteristics required by the end user of the fabric. Such processes include shearing, pressing and decatising to modify the fabric handle and appearance.

Depending upon the finish required, the wool fabrics may then either be shorn to remove surface fibres or brushed to create a pile of surface fibres. The brushed pile may be shorn to cut the pile fibres to a uniform height or to achieve a sculptured pattern.

The wool fabrics are then pressed using either flat, rotary or belt presses to achieve the desired appearance, lustre and handle characteristics. The effects of pressing are only temporary and hence the pressed fabric is then decatised to set the fabric. The set achieved in decatising should last through tailoring.

The decatised wool fabrics are relaxed by steaming, thereby reducing relaxation shrinkage in use. Finally, the finished fabrics are inspected for faults in a process known as perching.

15.2 Dimensional stability of wool fabrics

Introduction

Changes of dimensions during use, and the care-treatments of textile materials, particularly textile materials containing natural fibres, can be a major defect and is often the cause of unserviceability and consumer complaint.

The types of dimensional change that can occur when wool fabrics are treated during processing, or in use, can be placed into five general groups:

(i) relaxation
(ii) consolidation
(iii) swelling
(iv) felting, and
(v) hygral expansion due to changes in moisture content.

Relaxation shrinkage

Relaxation shrinkage occurs when the stresses or strains imposed during the processing of the textile materials are relaxed in water (or water plus soap or detergent), **without agitation.** Relaxation shrinkage is what might be called the first stage of shrinkage. This form of shrinkage is common to all fibre types and fabric constructions and is **non-reversible.**

Special finishing processes relieve these strains, e.g. tensionless drying of knitted goods and the crabbing process applied to worsted fabrics.

Consolidation shrinkage

The relaxation of residual strains in a fabric is frequently opposed by frictional constraints within the fabric brought about by fibre-fibre and yarn-yarn contacts. Further shrinkage; called consolidation shrinkage; can be brought about by gentle agitation in addition to simple soaking. This process is **non-reversible.**

In the case of knitted fabrics, consolidation shrinkage can occur with each washing. A bending of loops tends to occur due to the difference in twist at opposite sides of the loops. The strains are released upon washing and shrinkage occurs.

Swelling shrinkage

As can be seen from the data given in Table 15.1, when hydrophilic fibres absorb water the longitudinal swelling is negligible while the transverse swelling is appreciable. The transverse swelling can lead to dimensional changes known as swelling shrinkage. The problem is common to all hydrophilic fibres but is **reversible.**

Table 15.1 Swelling of Fibres on Wetting. Source: Pailthorpe, 2006.

Fibre Type	% Length	% Diameter
Nylon	1.2	5
Cotton	1.2	14
Wool	1.2	16
Silk	1.7	18
Viscose	3.5	26

Felting shrinkage

When untreated wool in any form is treated in water with soap/detergent it will swell and consolidate. If, however, some mechanical action is applied, particularly in an acid medium, the fibres can migrate and mat together tending to give, in the end, a solid mass of fibres. The result is an **irreversible** shrinkage called felting shrinkage.

Wool fibres, like most animal fibres, have a series of overlapping scales on the fibre surface. The scales point to the tip direction of the fibres, and the interlocking action of the scales, sometimes described as a ratchet-like action, causes the fibres to move preferentially in the direction of the root of the fibre.

Once felting shrinkage has commenced, it progresses as the washing time is increased but ultimately approaches a limit when the fabric has attained certain a limiting density. This density depends on the particular washing process being used. Factors determining the amount of felting shrinkage are:

(i) Fibre friction (in particular the Differential Frictional Effect)
(ii) Fibre elasticity
(iii) Fibre diameter
(iv) Yarn linear density.
(v) Yarn twist
(vi) Looseness of weave or knitted structure
(v) Certain finishes, e.g. chlorination and application of polymers in machine-washable wools

Hygral expansion

Hygral expansion is the change in dimensions that takes place in wool fabrics as a result of a change in regain. The dimensional changes caused by hygral expansion are reversible.

15.3 Finishing sequences

As discussed previously, the various finishing processes used for wool fabrics can be placed in two groups: wet finishing and dry finishing.

The wet finishing processes are not always carried out in the same order; but depend upon the type of wool fabric being processed and the nature of the required finish. Table 15.2 provides indicative finishing sequences for worsted, woollen and knitted fabrics.

Depending upon the finished fabric requirements, some processes may be combined; e.g. scouring and milling. On the other hand, the finisher will either use milling to achieve consolidation via felting, or use a shrink proofing treatment to prevent felting shrinkage.

Table 15.2 Examples of finishing sequences. Source: Pailthorpe, 2006.

Worsted woven fabric	Woollen woven fabric	Knitted fabric
Inspection, burling & mending	Inspection, burling & mending	Inspection, burling & mending
Scouring	Scouring	Scouring
	Carbonizing (If necessary)	
Crabbing	Crabbing	Crabbing
	Milling	Milling
	Shrinkproofing	Shrinkproofing
Bleaching	Bleaching	Bleaching
Dyeing	Dyeing	Dyeing
Hydroextraction	Hydroextraction	Hydroextraction
Back-rolling	Back-rolling	Back-rolling
Scutching	Scutching	Scutching
Drying	**Drying**	**Drying**
Conditioning	Conditioning	Conditioning
	Raising	Raising
Shearing/Singeing	Shearing/Singeing	Shearing/Singeing
Pressing	Pressing	Pressing
Decatising	Decatising	Decatising
Steaming	Steaming	Steaming
Final Inspection	Final Inspection	Final Inspection

15.4 Finishing processes

Inspection

The greige state fabric is inspected for various imperfections including yarn faults, weaving or knitting faults, knots, holes, stains, etc. If possible the faults are repaired, or marked for later identification. Knots are pulled to the back of the fabric, while small stains are removed with selected solvents and cleaning agents.

The term *mending* relates to the insertion of missed warp and weft yarn threads into a woven fabric and also to the correction of other faults by needlework, e.g. stitching. The term *burling* relates to the removal of imperfections.

Scouring

Depending on the fabric type, and its inherent dimensional stability, it may be necessary to pre-set the fabric before it can be processed in rope form in scouring and dyeing machines. Uncontrolled relaxation of worsted fabrics may cause severe distortion of the fabric during wet finishing, leading to cockling and running marks. For such a fabric, the fabric would be pre-set before scouring by crabbing or by decatising. However, pre-setting the greige fabric can set any stains in the fabric, making them very difficult to remove during scouring. One approach to solving this problem is to scour in open-width, followed by crabbing.

The aim of scouring is to remove the contaminants from the wool fabric and to relax the fabric. Depending upon the fabric type the spinning oil quantities present can vary from 1-2% (worsteds) to 10% (woollens).

As a result of fibre migration during scouring, wool fibres migrate to the fabric surface, creating a softer handle. Furthermore, consolidation of the fabric during scouring causes an increase in the cover of the fabric.

Wool fabrics may be scoured in either rope form or in open width form. The machines are designed to provide the correct degree of mechanical action to aid the scouring action. Rope scouring machines provide a better cleaning action but have the disadvantage that they can introduce permanent creases in some fabrics.

Rope scouring
The traditional rope scouring machine is known as the Dolly or Scouring Dolly.

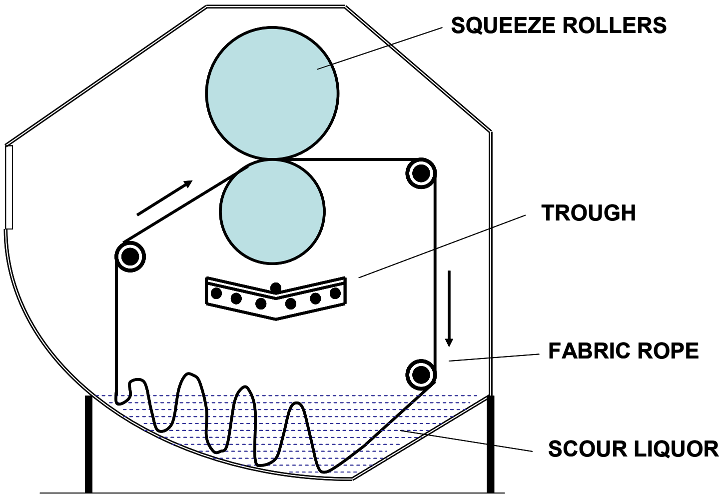


Figure 15.1 Dolly Scour. Source: Pailthorpe, 2006.

As can be seen in Figure 15.1, the fabric rope circulates in a clockwise direction, being lifted out of the scouring liquor, over the guide roller, through the squeeze rollers, and then on back into the scour liquor. The cycle then continues as the continuous rope is circulated at speeds of up to 80-100 metres/minute. The liquor squeezed out of the fabric rope by the squeeze rollers is collected in the trough underneath the squeeze rollers. During scouring, this liquor is returned to the bottom of the machine. However, during rinsing, the squeezed out liquor is directed to the drain.

Many of the disadvantages inherent in traditional Dollys have been rectified in modern machines. For example, both the top and bottom rollers, and the guide rollers, are driven and the pressure on the top roller can be controlled by either pneumatic pistons or springs.

Rapid rope scouring machines operate with speeds up to 220 metres/minute. As the fabric rope leaves the squeeze rollers, or scouring rollers, it is picked up by a doffing roller and propelled towards the rear wall of the machine. The compression of the fabric produced can provide substantial relaxation of the fabric.

Open width scouring
Open width scouring can be carried out in either batch or continuous scouring machines.

In the batch style of machine, the fabric, in open width, is processed in a closed loop. The fabric circulates in much the same way as in the Dolly, except that it is maintained in open width.

As shown in Figure 15.2, continuous open width scouring machines combine a series of washing, soaking, rinsing and cooling tanks to achieve the required dwell time and scouring action. There are several different scouring actions used in continuous open width scouring machines; ie, dips, squeezes and sprays, and sprays and suction slots.

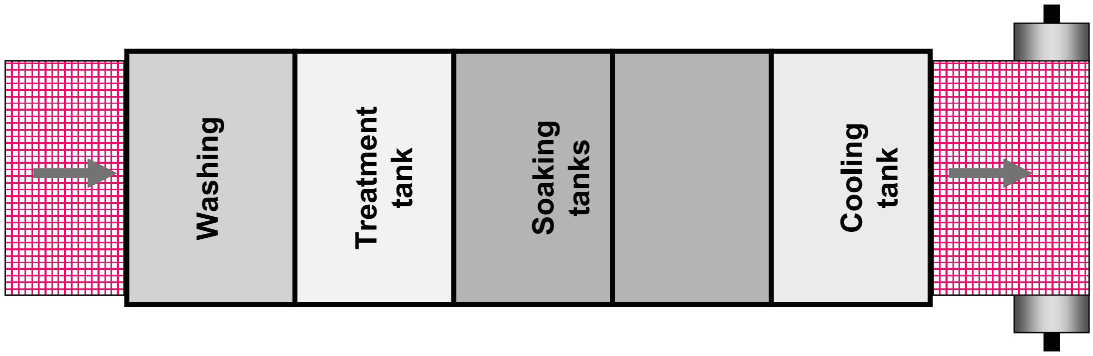


**Figure 15.2 Schematic of a continuous open width scouring machine.
Source: Pailthorpe, 2006.**

Carbonising

Carbonising is the chemical process used to remove vegetable matter impurities from a wool fabric. The vegetable matter may consist of burrs, seed and leaf matter from the shorn wool, and cellulosic fibres such as cotton and jute fibres.

Wools with high vegetable matter content are usually carbonised immediately after raw wool scouring (as discussed in Topic 4). Thus woollen fabrics made from carbonised wools do not usually require fabric carbonising. If vegetable matter remains in the wool after combing, then it may be necessary to carbonise such worsted fabrics. According to Rouette and Kittan, it is common practice in the USA to carbonise worsted fabrics; but this is rarely done elsewhere.

The carbonising process is based on the chemical differences between the protein of wool and the cellulose and lignins of the vegetable matter. Wool is relatively stable to high concentrations of acid while cellulose is readily hydrolysed by strong acids.

The wool fabric is first impregnated with a dilute solution of sulphuric acid (3-6%) containing a suitable wetting agent. The acidified fabric is passed through a carbonising oven in which the fabric is first dried (to evaporate the excess water and concentrate the acid) and then baked at 130-140^{o}C. During baking the sulphuric acid converts the cellulose to dehydrocellulose, which is brittle and can be removed mechanically by crushing and beating.

The sulphuric acid solution also contains a wetting agent, usually of the non-ionic surfactant type, to ensure that an even uptake of the acid by the wool occurs. The wool fabric must be uniformly treated by the sulphuric acid otherwise uneven dye uptake will take place during subsequent piece dyeing. The sulphuric acid reacts with the functional groups of the wool protein that act as dye sites for acid dyes or nucleophilic sites for reactive dyes, leading to an undesirable dye resist effect.

Crabbing

Crabbing is a pre-setting process used to impart the required amount of permanent set in wool fabrics. The wool fabric is flattened and maintained under tension; and then immersed in boiling water for 5-10 minutes. Finally, the wool fabric is cooled by passing the fabric through a cold water bath. The level of permanent set imparted to the fabric depends upon the pH and treatment time, and can vary from 40-85%. High levels of permanent set are required if the wool fabric is to be scoured and dyed in rope form.

Plain weaves are most prone to cockling and distortion. Crabbing permanently sets the weave and is essential for some kinds of wool cloth. It is, however, a preliminary finishing process.

Various methods and machines are used for crabbing. Crabbing fabric on traditional machinery is labour intensive and slow, and care is needed to avoid problems in later piece dyeing. Modern machinery, such as the Konticrab line for the continuous processing of piece goods, has largely overcome these problems (Figure 15.3).

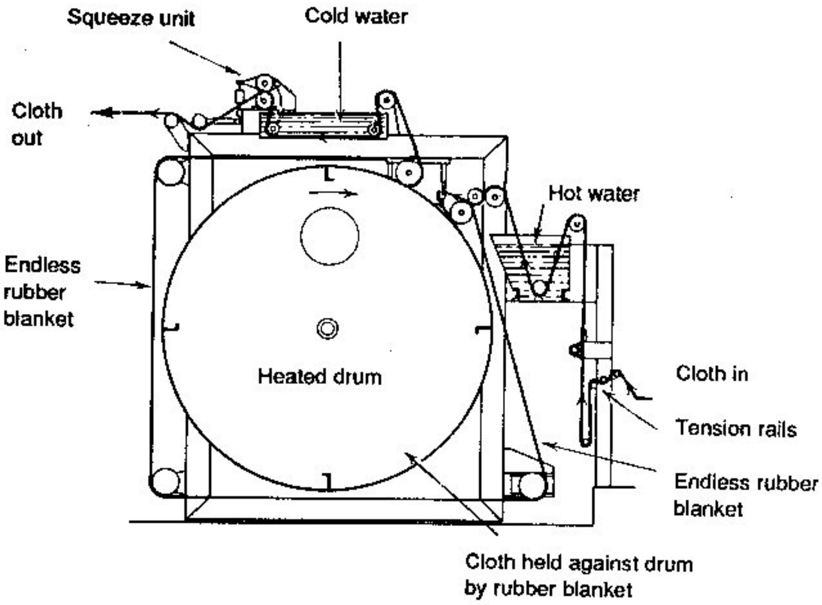


Figure 15.3 Konticrab continuous crabbing machine. Source: Pailthorpe, 2006.

The open-width fabric is first treated with hot water (80-100°C) or steam to relieve tensions. Then the fabric is set at the correct dimensions by passing it around the heated drum whilst held by the endless rubber blanket. As the fabric rotates, it is moistened, heated, and pressed. Finally the fabric is cooled by the cold water trough while stretched out, and batched ready for the next process.

Milling (or fulling)

Milling is the finishing process that makes use of the natural propensity of wool fibres to migrate and become entangled within the yarn and fabric structures. Milling, which is the controlled felting of woven or knitted fabrics, is also known as fulling. The scale structure of the wool fibres, combined with their elastic properties in aqueous media, favours preferential migration of the fibres towards their root ends. As a result, the fabric consolidates in both the warp and weft directions and becomes thicker; leading to a higher mass per unit area. Milling also achieves reduced air permeability, increased strength and a hiding of the weave structure (ie, high cover).

Milling is achieved by intermittent mechanical action in the presence of a suitable aqueous liquor. Milling can be carried out under mildly alkaline conditions or under strongly acid conditions, using a suitable lubricant. Sodium soaps or synthetic detergents are used for alkaline milling whereas formic acid is commonly used for acid milling. Milling machines include stocks, rotary milling machines and combined scour/milling machines.

Rotary milling machines

In piece milling the fabric is sewn into a tube, called bagging, with the fabric face protected inside the tube. Bagging allows the fabric rope to balloon, which prevents wrinkles and creases from being milled in. As shown in Figure 15.4, the fabric rope is moving in an anticlockwise direction, being lifted out of the milling liquor, through the draft gate, over the guide roller and into the throat piece.

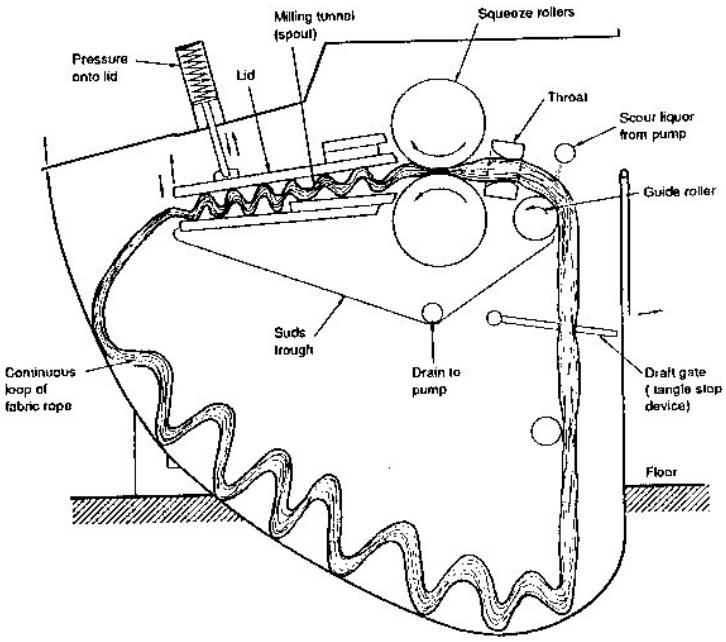


Figure 15.4 Rotary milling machine. Source: Pailthorpe, 2006.

Just before entering the throat, the fabric rope is sprayed with liquor. The fabric rope then enters the squeeze rollers and milling tunnel. The squeeze rollers and the milling tunnel, which is like a stuffer box, act mechanically on the wet cloth. The draft gate pulls lengthwise to reduce the cloth width and stops the squeeze rollers if a tangle occurs.

Three main milling systems are used in the rotary milling machine.

1. Grease milling. When soap-making yarn oils are used, alkali is added to the milling bath to saponify the oils. After milling, the fabric is scoured.
2. Soap milling. After scouring, the fabric is milled in dissolved soap noodles or synthetic detergent.
3. Acid milling. After scouring, the cloth is rinsed free of soap or detergent. The cloth is milled in a dilute solution of sulphuric acid. This method suits fabric dyed with dyes not fast to alkali.

Different substrates give varying results.

1. The higher the percentage of wool, and of fine wools in the blend, the faster the milling. Short wools mill more quickly than long wools.
2. Fabrics made from open-structured woollen yarns mill faster than those made from worsted yarn.
3. Low-twist yarns mill faster than high-twist yarns.
4. Tight fabric structures are slow to mill.

Process variables affect the milling:

1. The number of passes the fabric makes through the squeeze rollers, which can be set on modern machines.
2. The mechanical action of both the squeeze rollers, and the milling tunnel, which are machine controlled.
3. The milling bath temperature. Increasing the temperature makes fibres more mobile and so the milling rate increases. However, dye-bleeding is more likely at higher temperatures.
4. Liquor ratio. As the liquor ratio is reduced, the milling rate increases. Above a liquor ratio of 12:1, milling is slow. The draft gate and squeeze rollers control the amount of water in the cloth during mechanical action.

5. Concentration of the milling bath. Too much soap or detergent makes rinsing difficult, so just enough is used to make the cloth slippery.

Milling is progressive and must be stopped when the desired effect is reached. Milling ranges from a slight change in handle that makes fabric warmer and softer to the touch, to densely matted fabric. Prolonged milling makes the fabric shrink greatly, thicken, and become firmer and stronger. The yarn and fabric structure is almost completely obscured after prolonged milling.

The machine shown in Figure 15.4 can be used for scouring as well as milling. Scouring needs more water than milling. It can also be used for the dry milling of carbonised fabrics to crush charred vegetable matter.

Stocks

Milling stocks are wooden hammers that beat the wet fabric whilst it resides in a specially designed trough. Milling stocks are rarely used these days, but were once commonly used to hide running marks and other faults in woollen fabrics.

Shrink proofing

Whilst wool's natural propensity to felt and consolidate may be used to advantage in the milling process, for most other applications felting leads to undesirable shrinkage in wool fabrics. Shrink proofing is the finishing process that is used to minimise felting shrinkage in wool fabrics.

Shrink proofing treatments are commonly applied to wool in sliver form but may also be applied to wool in fabric form and to garments. The treatments may be divided into two main categories; being destructive and additive treatments. Destructive treatments use selected chemicals, e.g. chlorination, to soften and round off the scales on the wool surface; while additive processes use polymers to either coat and mask the scales or spot weld the wool fibres together, or both.

The most widely used process for the treatment of combed tops is the so called Chlorine-Hercosett process. The treatment process involves six steps, as follows:

1. Chlorination pre-treatment.
2. Antichlor and neutralisation.
3. Rinse
4. Hercosett polymer application.
5. Softener application.
6. Drying and curing of the polymer.

The chlorination pre-treatment is required to modify the exocuticle of the wool fibres so that the Hercosett polymer solution will spread evenly over the fibre surface. The treatment is a cold acid chlorination process employing sodium hypochlorite at pH 1.3-1.7. After chlorination the wool is neutralised with sodium carbonate solution and any residual chlorine is destroyed with sodium sulphite, followed by rinsing.

The wool tops are then treated with the Hercosett polymer, which is a polyamide epichlorohydrin based reactive polymer. The reactive polymer self-cross links during curing and hence is fixed to the fibre surface. The polymer coating effectively masks the scales of the wool and reduces the directional frictional effect. During washing the polymer swells, further reducing the fibre movement caused by the mechanical action of washing.

The softener application is necessary to prevent the polymer from sticking the wool fibres together, thereby improving processing performance. The softener also improves the handle of the Hercosett treated wool.

Additive shrink resist treatments for wool fabrics involve the application of aqueous solutions or emulsions of reactive prepolymers by padding, drying and curing. For example, the Sirolan BAP process is applied to wool fabrics after wet finishing and drying. The treatment works by both coating the wool fibres and by spot welding the wool fibres together, thus preventing fibre migration.

Bleaching

The objective of bleaching is to destroy the natural cream and yellow pigments in wool using either oxidative or reductive chemical processes to produce whiter wool. Bright white wool is required for certain market applications, e.g. baby's knitwear, and also for dyeing in pastel shades. Since wool itself can suffer damage by the action of oxidising and reducing agents, great care must be taken in formulating the bleaching recipes.

Bleaching may take place at the sliver, top, yarn or fabric stages of production. Hydrogen peroxide based bleaching recipes are commonly employed. Hydrogen peroxide is a very powerful oxidising agent, with its oxidising power increasing with increasing pH. Wool is sensitive to damage at high pH, so the pH of the bleaching bath must be controlled to a maximum of about pH 9.0-9.5. A typical hydrogen peroxide bleaching recipe typically includes hydrogen peroxide (1-4 volume), a wetting agent, a pH buffering agent and a stabiliser. The stabiliser is necessary because various heavy metal cations, e.g. copper, iron and manganese, can catalytically decompose hydrogen peroxide. The wool fabric is normally entered into the cold bleaching bath, the temperature is then raised to 40-50^{o}C, and held for the required bleaching time (2-6 hours). Hydrogen peroxide bleaching may be carried out in rope form or open with form; and can even be combined with scouring.

Wool may also be bleached using reductive chemicals, e.g. sodium dithionate (also known as sodium hydrosulphite or "hydros"). The wool is treated in stabilised aqueous hydrosulphite (2-5 g/l) at 45-65^{o}C for 1-2 hours in a sealed vessel. Whilst hydrosulphite bleaching is cheaper than bleaching with hydrogen peroxide, there is the problem of a residual smell. The residual smell can be eliminated by using hydrogen peroxide in the rinse bath.

Dyeing

Piece dyeing of wool fabrics may be carried out either in rope form or in open width form. The dyeing of wool is an extensive topic and is covered in Topic 13.

Hydro extraction

Wet wool fabrics can hold substantial amounts of water in the pores and spaces between the individual fibres and yarns. This water is held by a combination of surface tension forces and capillary action; and hence can be removed by mechanical force. From an energy savings point of view, hydro extraction is a much cheaper way of removing water than drying. For example, a pad mangle is 25 times less expensive than removing the same amount of water by drying using heat energy.

There are essentially three methods of hydro extraction in common use:

- mangling,
- centrifuges, and,
- suction slot.

Mangling

In mangling, the wool fabric is passed through a set of horizontally opposed pad mangle bowls. The hydrostatic pressure created at the nip between the two bowls squeezes the liquid water out of the fabric. For fabrics processed in rope form it is common to mangle twice, firstly in rope form and secondly in open width. Mangling first in rope form is performed to remove as much water as possible before opening to full width on the scutcher.

Centrifuges

Industrial scale centrifuges are used to hydro extract fabrics in rope form. It is important to feed the fabric rope into the centrifuge basket, or cage, to achieve a balanced load. Even so, the machines must be installed on solid foundations and be fitted with robust suspensions. Centrifuges can run at speeds of up to 1,500 revolutions per minute and generate substantial g-forces. G-forces of the order of 800-1600 are achieved in modern centrifuges.

Suction slot

For hydro extraction via suction slot, a high powered vacuum pump draws air through the fabric via a narrow slot that runs across the full with of the fabric. Suction slot hydro extraction is used on delicate fabrics that may be damaged by mangling or centrifuging.

However, suction slot hydro extraction is not particularly effective on wool fabrics, probably because of their relatively low air permeability. In addition, suction slot extraction has the highest energy costs of all three methods, and therefore is rarely used in the hydro extraction of wool fabrics.

Scutching

Scutching converts fabric from rope form to open width form. The twist in the fabric rope is detected electronically and the electronic signal is used to control an untwisting device which removes the twist from the rope. The now untwisted fabric rope then passes through opening rollers and guides to restore the fabric to the open-width form. The fabric may then be rolled up on beams or folded (cuttled) onto a mill trolley.

Back-rolling

When wool fabrics are scoured and dyed in rope form there is always the possibility of introducing creases or running marks in the fabric. Back-rolling, which is essentially crabbing (see above), is used to remove such running marks.

Drying

Drying is the process of removing water from the wool textiles using heat energy. The three methods of transferring heat energy from one object to another are conduction, convection and radiation; and all three methods are used in the textile industry.

In conduction (drum) dryers the fabric is brought into contact with a series of large diameter heated cylinders. Drum dryers are commonly used in the cotton industry but they have limited use in the drying of wool fabrics because of the risk of “glazing” the fabric surface that comes into contact with the hot metal surface.

The stenter

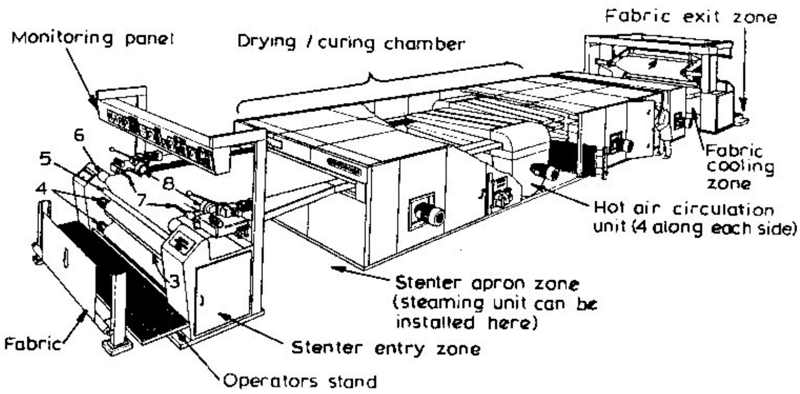
Convection dryers use hot air, heated by gas, to dry the textile material.

The stenter is a type of convection dryer, and is essentially a continuous open-width fabric-finishing machine. It is the most commonly used finishing machine for wool fabrics for a variety of reasons, including the ability to control the finished dimensions of the fabric. The fabric is held at each selvedge by pins or clips attached to two endless travelling chains that control the width. Stenters are used for:

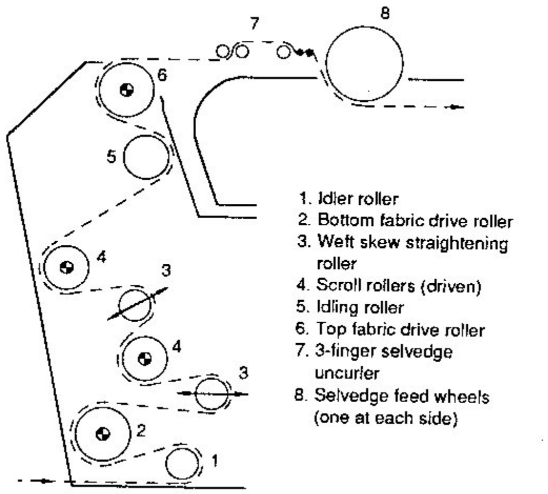
1. Drying piece-dyed or piece-scoured fabric.
2. Steaming and straightening the courses or grain of yarn-dyed knitted fabric that hasn't been wet processed. Stenters may also be used for weft straightening.
3. Heat-setting thermoplastic fabric both before and after dyeing. Before dyeing, it prevents creasing (pre-setting) and after dyeing, it is a final finishing treatment (post-setting).
4. Pre-setting and winding fabric onto the perforated cylinder for beam dyeing.
5. Fixing or curing chemical finishes that are applied by continuous add-on means.
6. Fixing dyes (thermosol process) that have been applied to fabric by continuous means.
7. Overfeeding, steaming, and width correction of fabric after dry-finishing processes such as raising and sanding.

Figure 15.5 shows the general layout of a 4-bay stenter, with the entry zone shown in cross section.

Fabric from a trolley, a batched roll, or from chemical add-on equipment passes over elevated rollers, and then descends to pass under the operator's stand. The selvedge feed wheels are each fitted with a disc brush to push the fabric edges onto the pins. The disc brush is guided by a photoelectric cell. More disc brushes in the apron zone push the fabric edge onto the pins.



(a) Overall view



(b) Cross section of entry zone

Figure 15.5 Four-bay stenter. Source: Pailthorpe, 2006.

The width of the fabric can be controlled by the separation of the chain tracks. The length dimensions of the fabric can be controlled by the relative difference in speeds of the feed rollers and the chain tracks. The wet wool fabric may be stretched by making the chains run faster than the feed rollers (underfeed); or allowed to shrink by making the feed rollers run faster than the chains (overfeed).

When wet wool is dried in this way the fabric becomes cohesively set. This type of set is quite temporary and is lost upon the next wetting out of the fabric.

Conditioning

As a result of over drying in the stenter, the dried wool fabric may contain less than its normal regain moisture for the prevailing atmospheric conditions. For example, at 65% RH the moisture regain of wool is typically 14-16% and this level of moisture content is required to achieve good results in subsequent dry finishing processes such as raising, cropping, pressing and decatising. Thus the dried fabric should be conditioned to normal regain before further processing takes place.

Wool fabric conditioning machines are based upon a number of principles including spraying water onto the fabric, passing moist air over the fabric and steaming the fabric (followed by cooling).

Raising (or brushing)

The aim of raising (or brushing) is to achieve desirable surface characteristics in the wool fabrics and to soften the handle. Raising is achieved using bristles (natural teazles) or bent metal wires to catch and lift fibres out of the plane of the fabric surface and make the fibres protrude as a pile or nap.

Since damp wool fibres are more pliable, and less fibre loss is suffered, the majority of wool fabrics are raised while damp. The typical wool regain employed would be 60-70% and lubricants may be also be used to reduce friction. Some fabrics may be pre-raised under damp conditions and then given a second raising after drying.

Examples of wool fabrics that are raised include blankets, fleecy fabrics and velours.

In raising, fabric surfaces are subjected to a tearing action that pulls fibres from the surface yarns and from within the fabric to form a raised surface (or pile or nap). The fabric is passed over rollers covered with strips of rubber-backed fabric in which bent wires are embedded, similar to those used in carding machines. The wire surface travels faster than the fabric and thus tears at the fabric surface. Metallic card wire raising “teazles” are shown in Figure 15.6.

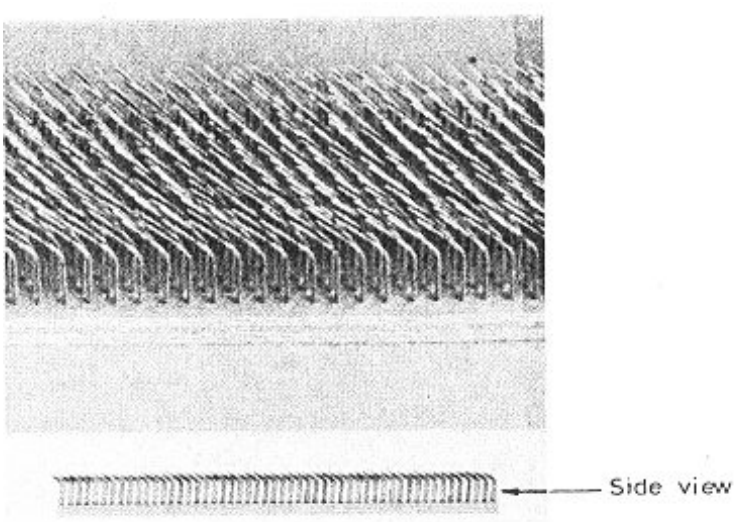


Figure 15.6 Metallic card wire raising “teazles”.
Photograph supplied by M. Pailthorpe, Canesis Network, Ltd.

Raising machines may be either single action or double action planetary machines.

Figure 15.7 shows the operation of a single action planetary raising machine. Pile rollers mounted around a large cylinder rotate very fast so that the surface speed of the wire is faster than the movement of the fabric. In a single action machine the orientation of the hooks of the metallic wires is the same, and the pile rollers rotate in the same direction, being anticlockwise in Figure 15.7. The inset shows the relative movement of the raising wire to the fabric so that the wire points dig into the fabric. The cylinder on which the planetary pile raising rollers are mounted rotates in the opposite direction (clockwise) to the anticlockwise fabric movement. Single-action machines have 24 to 36 pile raising rollers mounted on the main drive cylinder.

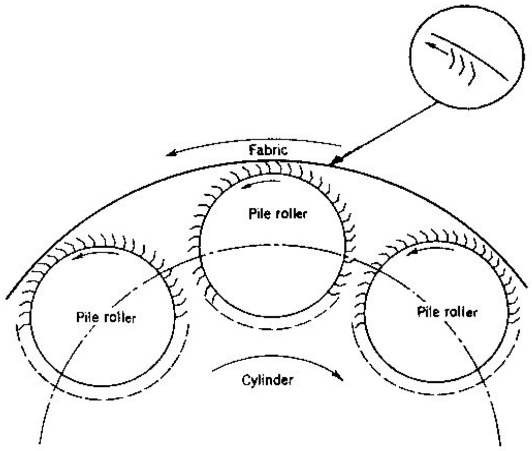


Figure 15.7 A single action planetary raising machine. Source: Pailthorpe, 2006.

Figure 15.8 shows a double action planetary raising machine, where alternate rollers have the metallic wire pointing in opposite directions. The insets show that the pile rollers pluck at the cloth in the same direction as in single action raising, while the counter pile rollers pluck in the opposite direction. The cylinder and counter pile roller speeds are much faster than the fabric feed and pile roller speeds. The cylinder rotates in the same direction (anticlockwise) as the fabric movement. Double-action machines have a total of 24 to 36 pile and counter pile raising rollers mounted on the main drive cylinder.

The fabric tension and the relative speeds of the fabric, rollers, and raising cylinder are varied to produce different effects.

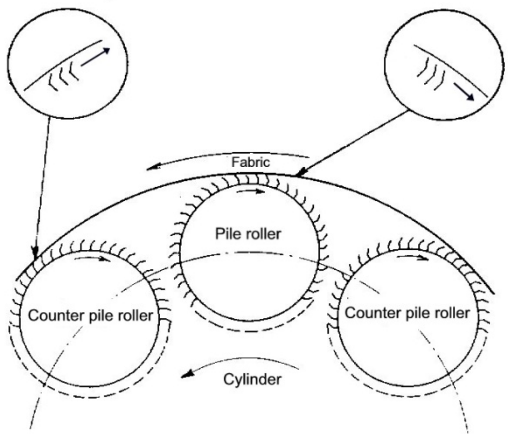


Figure 15.8 A double action planetary raising machine. Source: Pailthorpe, 2006.

The reasons for raising a fabric surface include:

1. Warmth: a napped surface insulates by increasing the still air space in the cloth.
2. Softness: a soft handle is important in baby clothes.
3. Appeal: raising improves the appearance of the fabric, partially blends colours, conceals the structure, and breaks the outline of patterns.
4. Water repellency: fibre ends at the fabric surface slow down wetting.

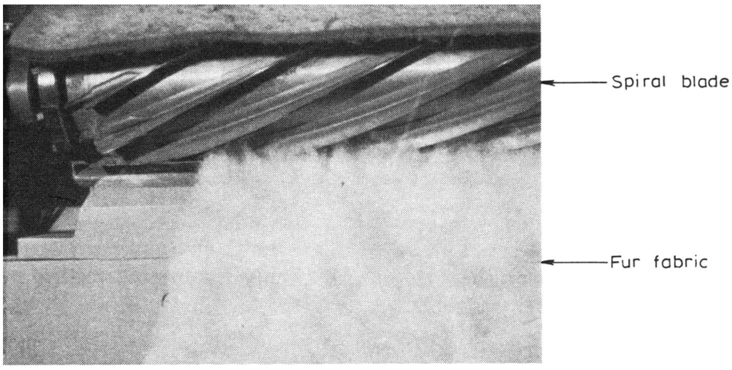
Many types of woven and knitted fabrics can be raised. The ease of raising the fabric and the length of the pile depend on how easily fibres can be pulled to the fabric surface.

Shearing (or cropping)

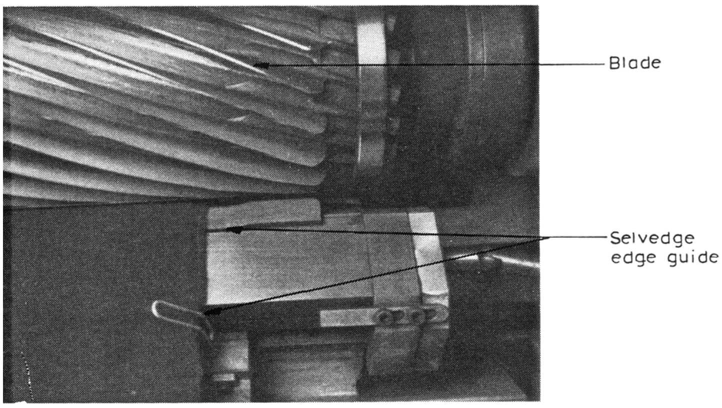
Shearing removes surface fibres to give the smooth finish required of fine worsted fabrics. Shearing can also be used to cut the pile of raised fabrics to an even length and hence appear more regular. This is called *levelling the nap*. Intermittent shearing can produce sculptured effects on pile fabric. A shearing machine works like a reel lawnmower, as shown in Figure 15.9.

Shearing uses a rapidly rotating cylinder with 14-20 helical blades to cut the fibres projecting from the fabric surface to an even, or uniform, length. The helical blades are rotated in close proximity to a fixed, or ledger, blade creating a continuous scissor-like cutting action. The length of the cut fibres is determined by the distance between the shearing bed and the fixed blade. The shearing bed may be either solid or hollow, the former providing closer cropping. The face only, or both sides, can be shorn at one or more of the shearing heads. A fibre-lifting roller-brush before each shearing roller makes the fibres stand up from the cloth surface. Suction devices remove fibre from the brushes, and remove flock from the shearing head.

Shearing faults are avoided by pushing the knots through to the back of the cloth and then first shearing the back of the cloth using a hollow shearing bed. Metal detectors are used to detect metal objects that may cause damage to the cutting heads. Modern machines may have two or more cutting heads so, for example, a three head machine can shear the back once and the face twice in a single pass.



(a) Fur fabric being sheared



(b) Selvedge guide for worsteds

Figure 15.9 The helical and fixed (ledger) blades of a shearing machine. Photograph supplied by M. Pailthorpe, Canesis Network, Ltd.

Singeing

Singeing removes protruding fibres from the fabric surface by burning them, leaving the fabric smooth and bare. Two methods are used to remove surface fuzz from fabric, ie:

- gas-flame singeing, and,
- plate singeing.

Gas flame singeing
Dry fabric passes in open-width at speeds of from 10 to 300 metres per minute over a row of fine gas flames. Machines, with suitable arrangements of rollers and burners, singe both sides of the fabric in one pass. Before singeing, the fabric is brushed and vacuumed to remove dirt and loose fibre. After singeing, the fabric passes through a water trough to quench any sparks on the cloth.

Plate singeing
In plate singeing the fabric passes over heated rounded plates to produce a clear and lustrous surface. Plate singeing is not as common as gas-flame singeing.

Whilst wool fabrics are resistant to burning, it is possible to remove the protruding fibres using a high temperature gas flame. Wool cloths are usually singed early in finishing but further wet processing tends to create more surface nap. This feature is made use of in wool/polyester fabrics because there is little or no polyester in the new nap. Unless singed, polyester fibres are very prone to pilling.

Singeing cannot replace shearing because singed wool fabrics need to be scoured after singeing. Thus the high productivity of singeing can only be exploited on greige state fabrics. Another advantage of singeing is that it removes fibres right down to the surface of the fabric structure.

Pressing

In pressing, a wool fabric is compressed under very high pressure between smooth heated surfaces, and is then cooled. The objectives are to improve the appearance and lustre of the fabric; and also to modify the handle by reducing its thickness. Pressing is really an ironing process mainly used for woven wool fabrics and may be used as preparation for decatising. The effect is only temporary because pressing only imparts cohesive set to the fabric and the effects of pressing are partially lost during steaming and completely lost when the fabric is wetted.

It is essential that the wool fabric to be pressed is at normal regain and is initially cool. Pressing then employs the combination high pressure and heat energy to achieve the desired result. The heat and regain moisture make the wool pliable, which allows the fabric to take up the configuration imposed upon it by the applied pressure.

Three types of pressing machines are used in the wool industry: the paper (or flat hydraulic) press, rotary press and belt press.

Flat pressing

In flat pressing, sheets of special glazed cardboard, called *pressing paper*, are placed alternately between fabric layers with special electrically heated plates interleaved at regular intervals. The fabric is dampened by water, mist or steam before pressing. The combination of moisture, heat, and applied pressure (~10-40 MPa) produce the ironed finish. The fabric is pressed twice, with the fabric folds from the first pressing positioned in the middle of the press for the second pressing. Flat pressing takes several hours to complete.

Rotary pressing

Rotary pressing is a continuous process in which cloth is pressed between a heated pressing cylinder and a heated press bed. Both the pressing cylinder and press bed are heated to about 120-135^{o}C. As can be seen in Figure 15.10 the fabric is fed in open-width past a metal detector, through a dampening unit (to achieve the ideal moisture content) and is then delivered to the pressing zone. After pressing the fabric is cooled and conditioned before being cuttled (as shown in Figure 15.10) or rolled up onto a beam.

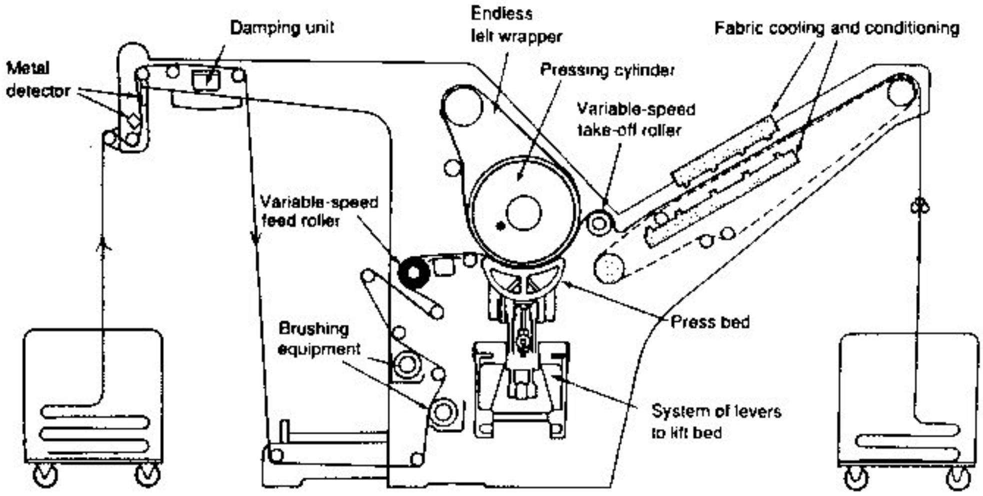


Figure 15.10 Side elevation of a rotary press. Source: Pailthorpe, 2006.

Rotary pressing is more economical than flat pressing, and a wider range of fabrics can be pressed, although on wool fabrics the result is not as good as that achieved with flat pressing. The endless felt wrapper shown in Figure 15.10 is extra, which, when used, makes the fabric less flattened, softer, and not as stretched.

While rotary pressing is more productive than flat pressing, it has the disadvantage that the fabric is under tension during pressing. Furthermore, the metal cylinder must be regularly etched to prevent it from becoming smooth. A smooth pressing cylinder would allow the fabric to slip, leading to a poor pressing result; however, the endless felt wrapper shown in Figure 15.10 overcomes this problem to some extent.

Belt pressing

Even so, in recent times, rotary presses have been superseded by belt presses. In belt pressing the fabric is sandwiched between a heated metal roller and an endless rubber belt. Since the metal cylinder and the belt are both moving at the same speed, there is no tension applied to the wool fabric during pressing. The rubber belt is under high tension, ensuring high contact pressure where the fabric passes between the cylinder and the belt. The pressing cylinder is heated to about 120-135^{o}C.

After pressing the fabric is cooled down by drawing ambient air through the fabric as it passes across a cooling table.

Decatising

The aim of decatising (also known as blowing, open blowing or decating) is to stabilise the properties of a wool fabric developed in finishing; including the lustre and handle achieved in pressing. It produces a smooth, wrinkle-free finish and lofty handle in woollen and worsted fabrics and in wool blends with man-made fibres. Heavier knits such as double jersey may be decatised.

Decatising can also be used to improve the crease-resistance of wool fabrics.

In decatising the fabric is interleaved with a cotton, polyester/cotton or polyester fabric and rolled up onto a perforated decatising drum (or roller) under controlled tension. The fabric is steamed for up to ten minutes and then cooled down by drawing ambient air through the fabric roll. The piece is then reversed and steamed again in order to ensure that an even treatment is achieved along the length of the fabric piece.

Decatising is usually the final finishing process, often carried out after steaming or some other shrinking process, to ensure dimensional stability. Decatising should last through garment making, and beyond if done under pressure. Most wool-rich woollen and worsted fabrics are decatised. Figure 15.11 shows a diagram of a traditional batch decatiser.

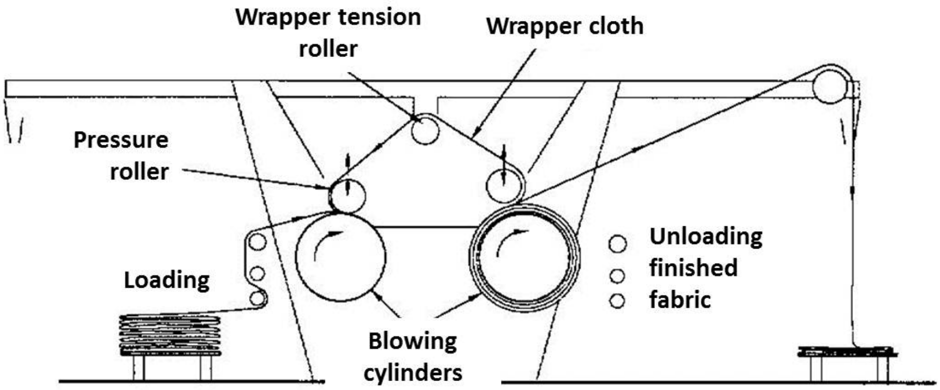


Figure 15.11 A traditional batch decatising or blowing machine.
Source: M Pailthorpe, 2006.

The perforated-metal blowing cylinders are wadded and covered with a special cotton or cotton/synthetic canvas wrapper. Steam can be fed to the inside of each cylinder. The wrapper cloth is tightly woven and is smooth on both sides, strong, and stretches very little under tension.

The dry fabric is loaded onto the cylinder with the wrapper, forming alternate layers of fabric and wrapper on the cylinder. While one cylinder is loading, the other is unloading. The fabric is fed in under minimum tension, while the wrapper rolls on under tension to compress the fabric.

Once loaded, the cylinder is flooded with saturated steam until it has penetrated all of the layers of the fabric and wrapper and then escapes. Free steam escapes for about 90 seconds, during which time the wool fibres become plastic as the cross-links within the fibres are broken.

The steam is then turned off and a pump draws cold air through the fabric into the cylinder. The cold air partially sets the fabric in its relaxed state by reforming the cross-links.

Wet fabric may be wet decatised. To give fabric maximum set, flatness, and lustre, the wrapper is wound on under maximum tension, and the fabric blown twice and then cooled. For a fuller, less firm handle, the fabric is compressed less, lightly steamed, and not thoroughly cooled before unloading.

Modern decatising machines include continuous decatisers and machines that operate under vacuum or pressure. These machines have controls for temperature and fabric tension plus safety features. Because of the short time steam is in contact with the fabric, continuous decatisers can only give wool fabrics a light finish which may suit acrylics, polyamides, viscose and blends of these with polyester and wool.

Both vacuum decatising and high temperature/pressure decatising provide a variety of finishes on wool fabrics. High-pressure decatising produces wool fabrics that shrink less than 1.5% during the large-scale making up of garments, which includes pressing.

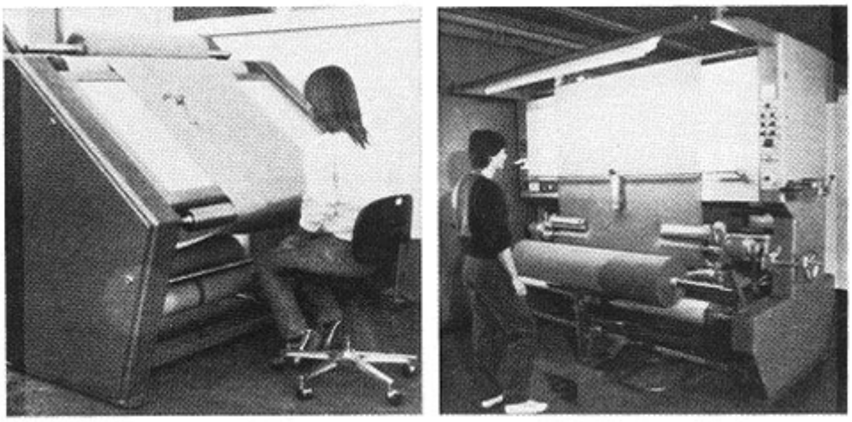
Steaming (or sponging)

As a final finishing process, steaming, also called sponging, is used to completely relax the fabric in order to achieve dimensional stability before sewing. London Shrinkage, a process in which the wool fabric was dampened with water and allowed to relax for 1-2 days, has been replaced by steaming machines. Steaming removes any tension put into the fabric during earlier finishing and hence reduces relaxation shrinkage. It may be carried out on woollens, worsteds, blends, knitted or woven.

The fabric is overfed by up to 20% into a steam chamber, where it is saturated with steam. It is then dried free of tension. The fabric is carried on screens and so the width is not controlled, as it is in stenters with pin chains.

Final Inspection

The final inspection of the fabric is carried out on a perch, so the process is known as perching. The fabric is run over an inclined or vertical translucent plate and illuminated from face and back, as shown in Figure 15.12. Serious faults are marked with “strings” or tags in the selvedge.



(a) Knitted fabric *(b) Woven fabric*

Figure 15.12 Perching machines. Photograph supplied by E. Wood, Canesis Network Ltd.

This is often the last quality control inspection. At final inspection, mending, spot cleaning, fault tagging, and downgrading are done as needed. Consistent standards of inspection, and between inspectors, must be maintained. Devices for measuring the length of rolls must be checked regularly, and inspection tables must be operated correctly so that fabric lengths, and hence invoicing, are correct.

Readings

The following readings are available on the web learning management system

1. oldandsold.com. An historical article on cloth finishing. Cloth finishing (originally published early 100s. Retrieved 20th August, 2006 from http://.www.oldandsold.com/articles04/textiles.22.shtml.
2. DeBoos, A., 2001. Australian wool, competitive through innovation. CSIRO Textile and Fibre Technology. Geelong, Victoria. Assessed 15th May, 2002. Retrieved August 20th, 2006 from http://www.tft.csiro.au.
3. Le, C., Ly, N., Phillips, D. and De Boos, A., Characterising the stability of the surface finish on wool fabrics, CSIRO, Textile and Fibre Science, Geelong, Victoria.
4. Tomasino, C., 1992, Chemistry & technology of fabric preparation and finishing, College of Textiles, North Carolina State University, which is available on the web at: www.p2pays.org/ref/06/05815.pdf. Retrieved 20th August, 2006. Chapter 3, Scouring (Pages 31-59), Chapter 4, Bleaching (Pages 60-71).
5. Hauser, P., 2003. Preparation, ITMA 2003. Journal of Textile and Apparel, Technology and Management, vol 3, issue 3, pp1-10. Autumn, 2003. Available on the web and retrieved 20th August, 2006 from http://www.tx.ncsu.edu/jtatm.click on "View Articles".
6. Tomasino, C., 1992, Chemistry and technology of fabric preparation and finishing. Ch 6, Mechanical aspects of chemical finishing; section II, Drying and curing and section III, Dryers and ovens, pp 90-96. College of Textiles, North Carolina State University, North Carolina, USA.
7. Tomasino, C., 1992, Chemistry and technology of fabric preparation and finishing. Ch 13, Mechanical finishing; section II, Raising, pp 232-239, section IV, Shearing, pp 239-240; and section VIII, Decating, pp 243-244. College of Textiles, North Carolina State

University, North Carolina, USA.

Summary

The objective of wool fabric finishing is to convert greige state fabrics into fabrics that have the properties desired and expected by the consumer. Wool fabric finishing processes are divided into two groups: wet finishing and dry finishing.

The wet finishing of wool fabrics groups together all of the aqueous based processes so that, in principle, the fabric needs to be dried only once. The objects of wet finishing are to remove the contaminants from the wool fabrics, and to relax any latent stresses and strains in the fabrics. Certain fabrics may need to be shrinkproofed to achieve machine washability. The wet finishing processes include scouring, crabbing, milling, shrinkproofing, bleaching and dyeing, all being aqueous based technologies. After wet finishing the fabric is hydroextracted and dried.

The objective of dry finishing is to develop the required properties in the wool fabric, including appearance, handle, lustre, set and dimensional stability. After drying the fabric is processed through the conditioning, raising, shearing, pressing, decatising and steaming.

Finally the finished fabric is inspected for faults on a perch, with the faults marked at the selvedge using strings or tags. The delivery contract between the manufacturer and the customer will specify the allowable number of faults per 100 metres. Faults in excess of the allowed number will suffer a penalty, e.g. one extra metre of fabric per fault.

References

Brady, P.R., 1997, CSIRO Wool Technology, A Guide to the Theory and Practice of Finishing Woven Wool Fabrics, Ed. P. R. Brady, 1997, ISBN 0 643 06525 0.

Connell, D.L., 2003, Chapter 11 – Wool Finishes: The Control of Shrinkage, in Textile Finishing, Ed. D. Heywood, Society of Dyers and Colourists, Hampshire, UK, ISBN 0 901956 81 3.

Rouette, H-K. and Kittan, G., 1991, Wool Fabric Finishing, Wool Development International, ISBN 0 9517154 1 0.

De Boos, A.G., 2003, Chapter 12 – Mechanical finishing of wool fabric; in Textile Finishing, ed. D. Heywood, Society of Dyers and Colourists, Hampshire, UK, ISBN 0 901956 81 3.

Levene, R., 1984, Chapter 4 - Wool bleaching, in Handbook of Fibre Science and Technology: Volume I, Chemical Processing of Fibres and Fabrics, Fundamentals and Preparation, Part B, eds M Lewin and S B Sello, Marcel Dekker, New York, ISBN 0 8247 7117 6.

Maclaren. J.A. and Milligan, B., 1981, Wool Science, The Chemical Reactivity of the Wool Fibre, Science Press, Sydney, ISBN 0 85583 091 3.

Miles, L., 2003, Chapter 2 – Drying and setting, in Textile Finishing, (ed.) D. Heywood, Society of Dyers and Colourists, Hampshire, UK, ISBN 0 901956 81 3.

Shaw, T. and White, M., 1984, Chapter 5 – The chemical technology of wool finishing, in Handbook of Fibre Science and Technology: Volume II, Chemical Processing of Fibres and Fabrics, Functional Finishes, Part B, eds M. Lewin and S. B. Sello, Marcel Dekker, New York, ISBN 0 8247 7118 4.

Glossary of terms

Back-rolling	The removal of creases and running marks from rope dyed fabrics.
Bleaching	The application of selected chemicals to increase the whiteness of wool fabrics.
Blowing	An alternative term for decatising.
Brushing	An alternative term for raising.
Burling	The removal of imperfections.
Carbonising	The removal of vegetable matter from the wool fabric.
Conditioning	The application of moisture to dried wool fabrics to achieve a regain of 14-16%.
Crabbing	A pre-setting process used to impart the required amount of flat set in wool fabrics.
Cropping	An alternative term for shearing.
Decatising	A setting process used to stabilise the properties of wool fabrics developed during finishing.
Drying	The removal of adsorbed water from wool fabrics by the application of heat energy.
Dyeing	The application of coloured compounds to wool fabrics.
Fulling	An alternative term for milling.
Hydroextraction	The application of mechanical force, or centrifugal force, or suction, to remove liquid water from wool fabrics.
London Shrinkage	A process in which the wool fabric is dampened with water and allowed to relax for 1-2 days.
Mending	The insertion of yarn into a woven fabric where the warp or weft is missing and also the correction of other faults by means of needlework.
Milling	The application of mechanical action to cause the required amount of fibre migration in wool fabrics.
Perching	An inspection process used to identify faults in the finished fabric.
Pressing	The application of force to improve the appearance and lustre of wool fabrics.
Raising	A mechanical process used to create a pile on the fabric surface.
Scouring	The removal of contaminants from the fabric by a washing process.
Scutching	A process used to convert fabric in rope form to fabric in open width form.
Shearing	The cutting of raised fibres to the desired height.
Shrinkproofing	The application of chemical and/or polymer treatments to wool fabrics to prevent felting shrinkage.
Singeing	The use of a high temperature flame to remove surface fibres from wool fabrics.