Major factors affecting conversion of cotton fibers into quality products
ABSTRACT

The efficient conversion of cotton fibers into quality products, i.e. yarns and fabrics, is the ultimate goal of the textile engineer. Ideally, the textile engineer will select a particular cotton, either alone or in combination with other cotton types, to obtain the desired yarn properties. The processing conditions during subsequent weaving and finishing also play a role in the production of quality fabrics. The quality of the final product, besides basic fiber properties, will also depend on the processing conditions used and the care taken during the entire processing cycle. The importance of realizing the full benefit of fiber properties, although well understood in theory, becomes difficult to achieve in practice due to a variety of factors, such as processing sequences, parameters, conditions and type of equipment employed. The continuous monitoring of processing parameters throughout the entire processing cycle is of paramount importance for the sustained production of high quality products. The problems associated with yarn and fabric formation will be discussed. Modern manufacturing practices, in terms of equipment, processing conditions and trends in enhancing the value of cotton fabrics, will also be discussed.

Introduction

The mechanical behavior of staple yarns and fabrics is strongly dependent on the properties of their constituent fibers. Cotton fiber properties, such as fiber length and its uniformity, strength, fineness, maturity and contamination besides color, determine its usefulness; therefore objective assessment of fiber properties has received considerable attention (Hunter, 1980; Bragg, 2000). Cotton, being a natural fiber, possesses inherent variations in all its major properties, attributed to breeding, crop management, environmental conditions and mechanical processing during ginning (Bragg, 2000). This inherent variation in fiber properties not only poses challenges in the measurement but also in subsequent processing. To mitigate the effect of this inherent variation in fiber properties to some extent, textile engineers blend two or more cottons to optimize the processing behavior. However, precise controls during downstream processing, modern spinning technology and the development of new yarn structures also contribute towards achieving the yarn quality suitable for quality fabrics. The processing conditions and kind of technology employed during weaving and finishing also play an important role in achieving the desired quality.

The processing factors, which affect the overall quality of the finished cotton products, are summarized as follows:

- Fiber quality, properties and contamination
- Ginning conditions
- Spinning technology and controls
  - Quality of opening and cleaning
  - Carding
  - Preparatory spinning conditions and processes, such as combing, drawing and roving
  - Spinning technology employed, such as ring, rotor, compact, air-jet and vortex spinning.
- Weaving technology and controls
  - Preparatory weaving conditions and processes, such as winding, warping and sizing
  - Weaving technology employed, such as shuttle looms, shuttleless looms, such as air-jet, projectile, rapier and multi-phase.
- Dyeing and finishing technology improvements for cotton
  - Technology employed and quality of preparatory finishing processes, such as scouring, bleaching, mercerization
  - Technology employed and quality of embellishing finishing processes, such as dyeing and printing
  - Technology and quality of finishing processes, such as resin-finishing, easy-care, wrinkle-free treatment, etc.

The success and quality of each of the downstream processes are much dependent upon the processing conditions and controls of the preceding processes. This underlines the importance of carefully monitoring the processing parameters throughout the entire processing cycle for the economical production of high quality products.

Fiber quality, properties and contamination

Fiber quality, properties and contaminants have a great influence on the final product, be it fabric or yarn. Cotton usually becomes contaminated by trash, such as leaf, bark and grass, due to exposure in the field and the harvesting method adopted. The trash content largely determines the type of cleaning equipment to be used in the blowroom, so as to obtain maximum spinning efficiency, with a minimum loss of fiber. The presence of an appreciable quantity of foreign matter results in greater waste loss during processing, reduces output and affects the quality of the product. The fine particles of trash, “pin trash”, also become the nucleus of neps during processing. This type of trash has a particularly adverse effect on rotor spinning since it builds up in the rotor groove and causes interference with the yarn formation process and increases wear on machine parts. Broken fragments of seed or shell can cause trouble in the fabric through the bleeding of coloring matter when wet with an alkaline liquor. Other foreign matter is always present, for example, leaf, stem, and other organic matter, and other elements such as
fungi and possibly enzymes of one type or another.

Over an extended period of many decades, literally hundreds of articles have been published on the subject of the relationship between yarn and fiber properties. Although high correlations and accurate predictive relationships were often arrived at in particular studies, as yet no relationships have been universally accepted for predicting the properties of cotton yarn from those of the fiber. It has become necessary to measure a wider range of cotton lint characteristics, for example, wax content, than those routinely measured. Fiber properties play an important role in determining the type of spinning process to be used. Cotton fineness is more important in rotor than in ring spinning, with the reverse being true for fiber length, the effects being attributed to differences in the fiber arrangement and alignment in the respective yarns. Strong rotor yarns can be obtained by using low micronaire, strong cottons, with fiber length and uniformity appearing to be of secondary importance. Fine and strong cottons improve the yarn strength and spinning performance for both ring and rotor spinning.

**Ginning conditions**

Hand picking yields relatively clean cotton, whereas mechanically harvested cotton is contaminated to a greater or lesser extent, depending upon whether spindle or stripper picking is used. Not all varieties behave the same, however, those with hairy leaves being less suited for mechanical harvesting because bits of leaf cling to the fibers. End breakage for hand picked cottons has been found to increase with increasing gin drying, whereas for machine picked cotton there is a minimum. Mechanically picked seed cotton generally comes to the gin containing more moisture than hand picked cotton and has to be dried in order to enable proper cleaning. Hot air is used for drying. If the cotton is picked too wet, i.e. over 12% moisture content, which may happen in the morning, or late afternoon, and is stored for any period of time, it will result in spotted or yellow stained fiber.

Saw ginning is used in most countries for ginning medium and short staple cottons. The roller gin is normally used for long staple cottons and is gentler than the saw gin. The main advantage of the saw gin is its high production rate and more uniform and clean lint which is obtained but it is not suitable for ginning extra long staple cottons. Saw gins produce shorter fibers and more short fibers, more neps and lower strength than roller gins. Nevertheless, only notable differences in the yarn properties of saw and roller ginned cottons respectively, relate to yarn appearance, where the roller gin produces only about half as many neps as the saw gin. During ginning the importance of maintaining good fiber length distribution cannot be over emphasized.

**Spinning technology and controls**

Optimum blending, opening and cleaning of cotton to remove foreign matter, seed coats and seed fragments are necessary to achieve good performance and quality during the subsequent processes. Naturally grown raw materials, such as cotton, are inhomogeneous in most of their properties, which affects the spinning performance. Besides optimizing the properties of the feedstock, the blending process is also aimed at optimizing the profit margin by the deliberate selection of different cotton varieties (Trutzschler Technical Bulletin on Installations for Fiber Preparation). Modern development in this area is mainly directed to automatic bale opening with continuous bale feed and multi-column mixers and metering technologies to optimize the homogeneity of mixing and ensuring the accuracy of the blending.

Modern cleaners are aimed at gentle fiber treatment and optimum cleaning efficiency based on economic considerations. Emphasis is laid on acquiring the highest possible level of good lint with negligible loss of good fibers. Figure 1 shows the removal of contamination, such as plant and leaf fragments, attributed to harvesting and picking practices, seed coat fragments due to ginning and neps due to the immaturity of fibers (lack of cell wall developments) during plant growth. This qualitative aspect of cleaning must complement economic considerations, such as the loss of good fibers. Figure 2 shows the saving for a typical spinning plant processing 10000 tons of cotton fiber per year. This saving is dependent on the cost of the cotton being processed.

The design considerations of opening elements have advanced in several respects. CLEONOMAT CVT4 from Trutzschler employs a constant suction principle to continuously remove the trash particles (through centrifugal force) and dust in cotton fiber. The integration of different stages of cleaning and control of fiber flow results in an improvement in the quality of processing. This ensures improved cleaning efficiency and thus better yarn quality and improved performance in ring and open-end spinning. Figure 3 shows a typical ‘Cleanogram’, which depicts the efficiency of trash and dust removal and the minimizing of fiber waste (Trutzschler Technical bulletin on Installations for Fiber Preparations).

Modern blowrooms can now open and clean cotton fibers efficiently and precisely irrespective of fiber damage during ginning. The blowroom is equipped with state of the art controls to ensure the supply of clean cotton at the rate of demanding modern cards. This alleviates the need for stop-go practices on the cleaning machine and thus ensuring gentle processing of the cotton fibers (Egbers, 1994).

Achieving controlled and reproducible card sliver
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quality, in addition to high productivity, is necessary to achieve consistency in yarn quality and spinning performance. The latest developments in high production cards are mainly directed to the improvement of sliver quality through an on-line monitoring system. Chute feeding of fiber tufts is now an integral part of the card. This has improved the evenness of the feeding into the card by eliminating faulty drafts caused by faulty or non-optimum settings. The controlled feeding of the web to the first licker-in is achieved by a special mechanism to eliminate short-term thickness (mass) variation and thus ensuring uniform feed to the licker-in system. Modern cards are equipped with a licker-in system with three rollers as opposed to the only one in conventional cards as shown in Figure 4. This set of rollers ensures the gradual opening of fiber tufts and the protection of the fibers from damage. For processing cotton, the first licker-in roller is equipped with short wires to gently pluck the tufts from the feeding device. The second and third licker-in rollers open the tufts further and to form a web for further carding. This gradual and gentle fiber opening is achieved through progressively increasing surface speed, finer clothing and increasing clothing angle from first to third licker-in. This helps in reducing nep generation before the actual carding action between the cylinder and revolving flat.

To achieve a higher quality of carding at higher throughput speeds, it is necessary that the carding action between the cylinder and flat be intensified. Therefore specific attention should be given to factors, such as cylinder speed, distance between flat and cylinders, fineness and shape of wires. Sudden intensified carding can lead to increased fiber damage; therefore, the strategy should be to incorporate pre-carding elements to gradually increase the actions (Schlichter, 2000). It is also important to remove trash before carding so that the cylinder and flat do not have to do much cleaning work. The distance between the revolving flat and the carding cylinder has to be precisely set for optimum carding and minimum waste of good fiber. Modern cards allow precision settings of the flat by electronic controls. This allows reduced downtime as well as reproducible results because manual adjustments of the flats are susceptible to errors. The grading of card wires is necessary to ensure quality carding at all times. New integrated grinding systems are becoming “intelligent” by providing all necessary information such as correct grinding date, ensuring precise re-grinding and re-adjustment of the flat without loss in productive time. Autolevelling and monitoring sliver regularity is now becoming almost a standard attachment on modern high production cards. Automatic nep counting at the doffer is an established technology incorporated in the grinding management system. The data from nep sensors help in deciding the most appropriate times to grind the flat wires without increasing the nep generation to unacceptable levels (Wxenham, 2000). This new approach now allows the grinding of flat wires to be pursued according to quality considerations rather than earlier practices of periodic grinding.

A new approach to save cost through process elimination is to incorporate a drafting system between the card doffer and coiler unit is reported to eliminate drawframe passages. This concept was used earlier in autolevelling systems. The drawback of these earlier systems was that they were operating in lower draft range, which was responsible for bunching of fibers. Only considerably higher drafts can align the fibers to become more parallel. The modern Integrated Drawframe (IDF) from Trutzschler, as shown in Figure 5, claims to have overcome this shortcoming of lower draft. A draft up to 300% is possible with a delivery speed of 500 m/min with a permanent monitoring of sliver quality by sensors. Improved straightening of fibers in the card sliver must result in improved yarn strength as shown in Figure 6. The process compares well with conventional carding followed by two passages of drawframe as shown in Table 1. This process reduction advantage, however, is deficient in incorporating the doubling and drafting action, which takes place in during full drawframe processing. The lack of doubling reduces the potential of mixing fibers, however, this is more a problem of effective raw material management rather than of spinning preparation. This may require a new design approach for incorporating double doffers on the card to improve the productivity still further. The direct link between card and drawframe is another step forward in a new design consideration in spinning. Interest in such developments, however, will be much dependent upon the future requirements of spinning mills to cut production cost.

In conventional drawframes, besides increased productivity through twin delivery and automatic can changing, autolevelling has become a standard feature to control sliver evenness. The primary function of the autolevelling equipment is to reduce, if not eliminate, all short-term mass variations present in the feeding slivers. Figure 7 shows a schematic diagram of the open loop control autolevelling principle. The thickness of the incoming slivers from the feed is measured with a pair of sensing rollers. The values are measured until the measured sliver section reaches the nip point of the main drafting zone and the draft ratio is changed accordingly by dynamic servo drive to compensate for even the smallest deviations. The output sliver from the front drafting roller is monitored by an independent control system to ensure the desired evenness of drawframe sliver.

**Compact or condenser spinning**

All the new spinning systems, particularly rotor and airjet spinning, considered as breakthroughs, were developed during the past few decades, and were aimed at improving spinning productivity. However, ring spinning has always remained at the forefront, both as the most popular spinning process and as a quality benchmark. Ring-spinning frames produced by different textile machinery manufacturers may differ in re-
spect of their engineering design—which may be evaluated in terms of reliability, spindle speed, power consumption, maintenance, repair etc. However, even today little difference can be found in terms of the technological principles employed. Compact spinning represents a new process using the basic components of the ring spinning system (Artz, 1997, 1998, 2001; Stalder, 2000; Hechtl, 1996) but producing better yarn quality through the compacting of the yarn structure. This compacted novel structure produces yarns with higher strength and elongation and reduced hairiness.

During the process of roller drafting, as employed in conventional ring spinning, the effective control of fibers, particularly short fibers, is an essential factor. The short fibers (shorter than the nip to nip distance of the main drafting zone) remain uncontrolled as they leave the grip of the rollers. The speed and movement of short fibers between the nips of the main drafting zone must be controlled so that the fibers get aligned to the core of the yarn and thereby contribute to better yarn strength and evenness. In most modern drafting systems, this task is accomplished by aprons that guide the fibers to the nip of the delivery roller. This shorter uncontrolled distance between the aprons and the delivery roller has led to better yarn uniformity. In practice, during the drafting process the width of the fiber flow is greater than the spinning triangle in conventional ring spinning as shown schematically in Figure 8. The figure shows the delivery end of the drafting zone with the subsequent yarn formation zone (Artz, 1997). The spread of the fibers in the drafting system is B, just before the nip of the delivery nip line as shown in Figure 8. This spread (or width) of fibers, B, which is several times the diameter of the yarn to be spun, depends on various spinning parameters, such as yarn count, roving twist, type of drafting system and amount of draft. The draft in the main drafting zone plays the major role in determining the width of the fiber streams emerging from the delivery end. Immediately after the fibers emerge from the nip of the drafting system, the yarn formation process begins. The fibers from the front roll nip are collected in the spinning triangle and integrated into the yarn structure by the twist imparted by the rotating spindle. For a given yarn count, the width ‘b’ of the spinning triangle depends upon the spinning tension, P, exercised by the rotating end, and is, in fact, inversely proportional to the spinning tension. The higher the spinning tension, the lower the width of the spinning triangle and vice versa. In ring spinning, this difference (B – b) is always greater than zero and therefore the spinning triangle cannot capture all the fibers delivered by the front nip. As shown in Figure 8, many peripheral fibers emerging from the nip of the delivery rollers are either lost or are so uncontrolled that they are only loosely attached to the yarn being twisted in the spinning zone. Therefore, the structure of the ring spun yarn is far from ideal, since many such loosely embedded fibers do not contribute to the yarn strength and also increase the yarn unevenness. In general, the strength of the spinning triangle is only about one third of the strength of the yarn being spun. This is attributed to the fact that the fibers in the center of the spinning triangle are practically without any tension, so they are bound together without suffering any elongation, whereas the fibers from the center of the ribbon to the outer side of the spinning triangle suffer increasing tension. The fibers at the edge of the spinning triangle have to withstand all the spinning tension imposed during the process of yarn formation. Obviously, the short fibers within the spinning triangle do not contribute towards the strength of the spinning triangle. Thus, the spinning triangle is a potentially weak spot and adversely affects the process stability (Olbrich, 2000).

In principle, the problems associated with the spinning triangle in conventional ring spinning should be eliminated if better yarn is to be produced. Some concepts in this direction were advanced by the Fehrer/Rieter and the ITV processes (Artz, 1998). In the former, the compaction was achieved by suction on to a perforated steel drum and in the latter by means of perforated ribbon aprons. More recently compact spinning frames became commercially available as Rieter’s Com4® and Suessen’s Elite® as shown in Figure 9. Both systems have attempted to eliminate the shortcomings of the yarn formation process in conventional ring spinning by reducing the adverse impact of the spinning triangle. An intermediate condensing or compacting zone is introduced between drafting and yarn formation. In this condensing zone, the drafted fibers are compacted by means of aerodynamic forces as shown in Figure 10. The condensing of the width of the fiber streams, B, is achieved, and it is converged to the width of the spinning triangle, b, such that the difference (B – b) tends to zero. This has led to the formation of a negligibly small spinning triangle or it is virtually eliminated. Therefore, all the fibers delivered by the front nip line are collected by the spinning triangle and thereby fully integrated into the twisting yarn. This has also led to a virtually perfect yarn structure of the compact spun yarn. All fibers are arranged parallel to the core and twisted together thus contributing fully to the yarn properties.

The technological advantages that resulted from such compact yarn structure are:

(a) Improvement in yarn strength and elongation
(b) Drastic reduction in yarn hairiness
(c) Improved abrasion resistance of the yarns

The improved attributes of compact spun yarn provide major advantages for downstream processing, such as the winding, warping, sizing and weaving operations (Artz, 1997; Olbrich, 2000).

Weaving technology and controls

Modern high productivity winding machines with electronic yarn clearers, electronic splicing and sens-
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Biotechnology is one of the key technologies – if not the key technology – of the 21st Century. Today, new processes and products are closely linked with biotechnology, the latter offering diverse possibilities to replace conventional processing procedures and at the same time, improve product quality. Enzymes are playing a major role in this regard as far as cotton is concerned and Table 3 shows that many textile finishing processes are already enzyme based (Böhringen and Rupp, 2000). Amylases have long been used for the starch desizing of cotton. Cellulases are used for bio-polishing (glazing) of woven cotton fabric surfaces. Cellulases are already replacing the conventional stone wash process (bio-stoning) in jeans production.

Other developments taking place in the biotechnology area to produce new or improved textile products are shown in Table 4. Replacing conventional processes with new types of enzymes, e.g. extremophile micro-organisms, which can be used at higher temperature and pH values, is an exciting development. The in-situ generation of biotechnological dyes and auxiliary agents can also revolutionize application procedures and augers well for the quality improvement of cotton products.

Multifunctionality is, as mentioned previously, a prerequisite as far as the market is concerned. Table 5 depicts the future technologies involved that will give multifunctional properties to cotton textiles (Nelson, 2001; Cernat et al., 2000; O’Brien and Aneja, 1999; Anonymous, 2002; Shroff, 2001; Knittel and Schollmeyer, 2000). Technologies, such as supramolecular chemistry, biopolymer systems, encapsulation, grafting and nanotechnology, are under investigation to improve comfort (e.g. regulation of a micro-climate against the skin) and protective (antibacterial, antifungal, UV resistant, water and stain repellency etc.) properties of cotton. The successful development and implementation of these technologies will allow cotton to compete in the “Smart Textiles” market with synthetic fiber products in the medical, protective, sportswear and geotextiles fields.

Finally, another issue interrelated with the production of quality products is that of cleaner production. The cotton processing industry, locally and abroad, has made great strides in “cleaning up” its act. Not only are major savings possible in e.g. water and energy consumption, but products with an eco-label e.g. the EU Flower, have been produced. Outstanding achievements in this regard are given in Table 6. The recently launched EU sponsored “Best Available Technologies“ documents specify optimum processing procedures for each stage of the pipeline. The SCORE system, which allows companies to establish existing levels of harmful substances in their wet processing areas and to adapt usage to reach acceptable levels, is well established. Eco-labeling and improvement projects comprising liquor displacement, re-cycling and re-use of water, chemical-free rinsing, etc. are well established in the processing pipeline of cotton.

There is no doubt that cleaner production makes good business sense.
References


Table 1. Comparison between conventional and shortened processes.

<table>
<thead>
<tr>
<th></th>
<th>Conventional process a</th>
<th>Shortened process b</th>
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<tbody>
<tr>
<td>Yarn CV%</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Thin Places (≤50%)</td>
<td>56</td>
<td>54</td>
</tr>
<tr>
<td>Thick Places (≥50%)</td>
<td>105</td>
<td>77</td>
</tr>
<tr>
<td>Nep (≥280%)</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Tenacity (cN/tex)</td>
<td>13.1</td>
<td>12.6</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>6.0</td>
<td>6.1</td>
</tr>
</tbody>
</table>

a Conventional Process: Carding – Drawing 1 – Drawing 2
b Shortened Process: Carding – IDF – Drawing 2 (breaker drawing eliminated)

Yarn: 100% cotton, Ne 6.5 (Nm 11)
(Source: Schlichter et al., 2000).
Table 2. Relative production rates of weaving machines.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Relative Production Rate</th>
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<tbody>
<tr>
<td>Automatic loom with shuttle</td>
<td>1</td>
</tr>
<tr>
<td>Shuttleless loom</td>
<td></td>
</tr>
<tr>
<td>(i) Rapier</td>
<td>2</td>
</tr>
<tr>
<td>(ii) Projectile</td>
<td>3</td>
</tr>
<tr>
<td>(iii) Air-jet</td>
<td>10</td>
</tr>
<tr>
<td>(iv) Multiphase</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3. Use of enzymes in textile finishing.

- Desizing (amylases) → Combined desizing and bio-preparation
- Bio-preparation (pectinase) → Combined bio-preparation and bio-polishing
- Bleaching → Single bath bio-preparation and dyeing
- Dyeing → Single bath bio-polishing and dyeing
- Finishing (cellulases)

Table 4. Enzyme based research and development taking place.

- Optimization of the use of technical enzymes for conventional processes.
- Replacing conventional processes with the aid of new types of enzymes (extremophile microorganisms) These enzymes can be used at higher temperatures and pH values.
- Preparing enzymes-compatible dyestuff formulations, textile auxiliary agents and chemical mixtures.
- Producing new or improved textile product properties by enzymatic treatment.
- Preparing biotechnological dyes and textile auxiliary agents, which can possibly be, generated in-situ during the application process.
<table>
<thead>
<tr>
<th>Technologies of the future for the modification of cotton to produce quality products.</th>
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<tr>
<td><strong>Table 5. Technologies of the future for the modification of cotton to produce quality products.</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Challenges</th>
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</thead>
<tbody>
<tr>
<td>High UV absorption</td>
<td>Prevention of oxidative and photodestructive chemicals. Color of photodynamic couplings of transgenic cotton. Which offer enhanced photosynthesis with various processes as well as the application of nanoparticles and nanoscale structures to improve the efficiency of photosynthesis. Nanotechnology techniques will include measurement of gases that allow for the formation of gases.</td>
</tr>
<tr>
<td>Healthy leaves &amp; enhanced disease resistance</td>
<td>Prevention of chlorophyll loss as well as the defense against pests and pathogenic bacteria. The defense is effective against the release of healthy leaves.</td>
</tr>
<tr>
<td>Adequate growth</td>
<td>Further developments and refinements in microencapsulation are likely to increase productivity, especially in enhancing durability.</td>
</tr>
<tr>
<td>Effuse energy</td>
<td>Prevention of oxidative stress such as the action of free radicals.</td>
</tr>
<tr>
<td>Efficient energy</td>
<td>Prevention of oxidative stress such as the action of free radicals.</td>
</tr>
<tr>
<td>Wettable leaves &amp; enhanced disease resistance</td>
<td>Prevention of oxidative stress such as the action of free radicals.</td>
</tr>
<tr>
<td>Possible products</td>
<td>Prevention of oxidative stress such as the action of free radicals.</td>
</tr>
</tbody>
</table>
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Table 6. Cleaner cotton textile production activities.

- BEST AVIALABLE TECHNOLOGIES (BAT) – highlighting the best or optimum processing procedures to follow to achieve environmental friendliness.

- SCORE SYSTEM – characterization of substances having a negative impact on the environment of industrial sewage.
  - discharged amount of substance
  - biodegradability
  - bioaccumulation
  - toxicity

- ECO LABELLING – EU Flower

- DEMONSTRATION PROJECTS
  - water savings by liquor displacement
  - water re-use through process integration
  - chemical free rinsing
  - salt and color reduction
  - reclamation and re-use of rinsing water

- NATIONAL CLEANER PRODUCTION CENTRE (PRETORIA)

- LINKAGE CENTRE (CAPE TOWN)

Figure 1. Removal of contaminants.

![Removal of contaminants](image)
Figure 2.
Saving due to reduction in waste.

Figure 3.
Cleaning efficiency.

Figure 4.
Licker-in system.
**Figure 5.**
Schematic of a drawing unit between card doffer and coiler.

**Figure 6.**
Effect of draft on span length.

**Figure 7.**
Schematic of auto-levelling principle.
Figure 8. Spinning triangle.

Figure 9. Condenser spinning systems.
**Figure 10.**
Compacting of a spinning triangle.

Conventional
B > b

Compact spinning
B = b