REFERENCE BOOKS OF TEXTILE TECHNOLOGIES

finishing

by Pietro Bellini, Ferruccio Bonetti, Ester Franzetti, Giuseppe Rosace, Sergio Vago

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FONDAZIONE
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Foreword

I am pleased to present the third edition, extensively revised and updated by the Authors, of the fifth "Notebook" on textile machine technologies in the textile finishing sector, which Fondazione ACIMIT decided to prepare for the use of the Italian textile technical institutes and of the universities with degree courses in textile engineering.

The exigence of working out these Notebooks emerged in 1999 from a series of meetings which Fondazione ACIMIT started with the headmasters of various technical Institutes and with their teachers within several initiatives aimed at intensifying the relations of this Foundation with the school world.

In fact we were informed that the text-books available at that time were no more abreast of the steady and rapid technological development which had characterized the textile sector in these years.

In order to publish Notebooks which respond as much as possible to students' learning needs, Fondazione ACIMIT decided, in accordance with the schools' headmasters, to entrust a group of teachers of their Institutes with the realization of these Notebooks, a demanding task which they accepted with great enthusiasm.

The success of this initiative – the total run exceeded 16.000 copies - convinced us also of the opportunity to translate the Notebooks into English, Chinese and Arab in order to ensure their circulation also with the leading foreign textile institutes and universities, in particular in the countries with high textile vocation.

We shall highly welcome any suggestion and correction presented by teachers, company technicians, etc,. which can permit us to improve these publications and to enhance their efficacy.

October 2006 *Paolo Banfi, President of Fondazione ACIMIT*

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The ACIMIT Foundation wishes to thank the headmasters and the teachers of following Institutes:

- ITIS Buzzi – Prato
- ITIS Carcano – Como
- ITIS Casale – Torino
- ITIS Facchinetti – Busto Arsizio (Varese)
- ITIS Leonardo da Vinci – Carpi (Modena)
- ITIS Leonardo da Vinci – Napoli
- ITIS Marzotto – Valdagno (Vicenza)
- ITIS Paleocapa – Bergamo
- ITIS Q. Sella – Biella
- ITIS Varese – Varese

Without the prompt and active co-operation of headmasters and teachers of these Institutes, the publication of these Noteboooks would have been never possible.

* * *

In particular, the “Finishing” Notebook was written by following teachers:

- Prof. Pietro Bellini
  Graduate in 1974 in Chemistry at the Università Statale di Milano; from 1977 teacher of Textile Chemistry and Fabric Finishing at the technical institute ITIS Carcano in Como and since 1994 teacher at this institute of Dyeing Chemistry; contributor to the association “Tessile di Como”.

- Prof. Ferruccio Bonetti
  Graduated in 1975 in Chemical Engineering at Politecnico di Milano. Since 1983 teacher of Dyeing Technologies and Textile Finishing at the technical institute Paleocapa in Bergamo. Since 1999teacher of “Textile and Dyeing Chemistry”within the curriculum for Textile Engineering degree at the Università di Bergamo.

- Prof. Ester Franzetti
  Graduated in Chemistry and Pharmaceutical Technologies at theUniversità di Milano; since 1985 teacher of Chemistry, Textile Chemistry and Textile Finishing at the technical instituteITIS Varese in Varese.

- Prof. Giuseppe Rosace
  Graduated in 1991 in Chemistry at the Università di Messina; in 1995 doctor’s degree in Chemical Sciences at the Università di Bologna. Since 1996 teacher of Textile Chemistry at the technical institute ITIS Paleocapa in Bergamo. Since 2001 teacher of “Finishing technologies for textile materials” within the curriculum for Textile Engineering at the Università di Bergamo.

- Prof. Sergio Vago
  Graduated in 1976 in Chemical Engineering at the Politecnico di Milano. From 1978 to 1991 teacher at the technical institute ITIS Carcano in Como, where he teaches Dyeing Chemistry since 1998.

ACIMIT Foundation wish to thank all above mentioned eminent personalities for their extensive and enthusiastic contribution.

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INTRODUCTION

The aim of this book is to supply the most comprehensive and global insight into textile finishing processes. Since the subject is exceptionally extensive and complex, this book may appear limited to the experts working in this sector.
As far as students are concerned, we hope that this book will offer them an essential background, a basis to be extended by further studies.

Textile finishing usually includes treatments such as scouring, bleaching, dyeing and/or printing, the final mechanical or chemical finishing operations, that during this stage are carried out on textile products (staple, sliver or top, yarns or filaments, woven or knitted fabrics) to enhance their basic characteristics like dye penetration, printability, wettability, colour, hand, and appearance.
By textile finishing, we also mean all the processing operations that, though included in the so-called finishing stage, are generally applied to the fabrics to improve their appearance, hand and properties, at times in accordance with their field of application.
The finishing stage plays a fundamental role in the excellency of the commercial results of textiles, which strictly depend on market requirements that are becoming increasingly stringent and unpredictable, permitting very short response times for textile manufacturers.
The latest machines on the market used for finishing operations generally offer multi-purpose applications; the flexibility and versatility features of these machines are uninterruptedly evolving to grant excellent consistency of results.

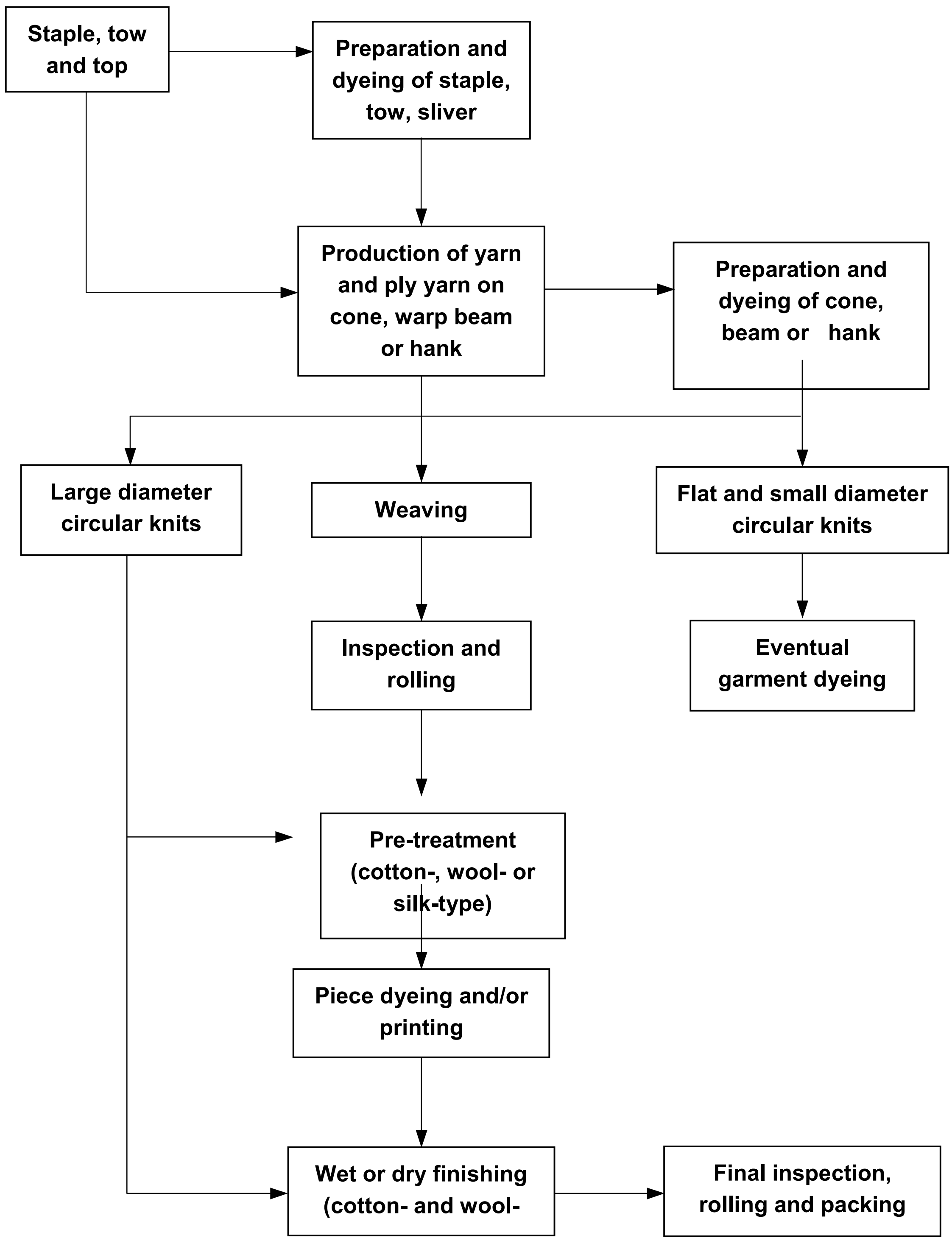
Finishing operations can be carried out by means of discontinuous, continuous and semi-continuous systems.

- *Discontinuous or batch-type systems*: all the operations are carried out on a single machine; it is therefore necessary to load the machine, carry out the treatments following a predetermined cycle, unload the machine and finally wash it thoroughly before starting a new cycle. This working process is extremely flexible and is suitable for processing small lots: for example, it is possible to carry out a scouring treatment on a single machine, then a bleaching treatment followed by a dyeing process. For the production of large lots, the discontinuous process is labour-intensive, i.e. it requires many operators to load and unload the material; it also entails long processing times and results that can vary from one batch to the other.

- *Continuous systems*: the operations are carried out by means of a series of machines; every machine carries out always and solely the same process. Every machine is assembled according to specific production requirements. A system like this entails high start-up costs and a complex setup but, once the system has started, requires a smaller staff and grants excellent repeatability and high output rates; continuous systems are therefore suitable for manufacturing large lots of products with the highest cost-efficiency.

- *Semi-continuous systems*: in these mixed systems, several operations are carried out with both continuous and discontinuous machines. For example, a continuous pad-batch machine is used to wet the fabric and a discontinuous system is successively used for other treatments. These mixed systems are suitable for processing small and medium lots; they require reasonable start-up costs and grant quite good reproducibility.

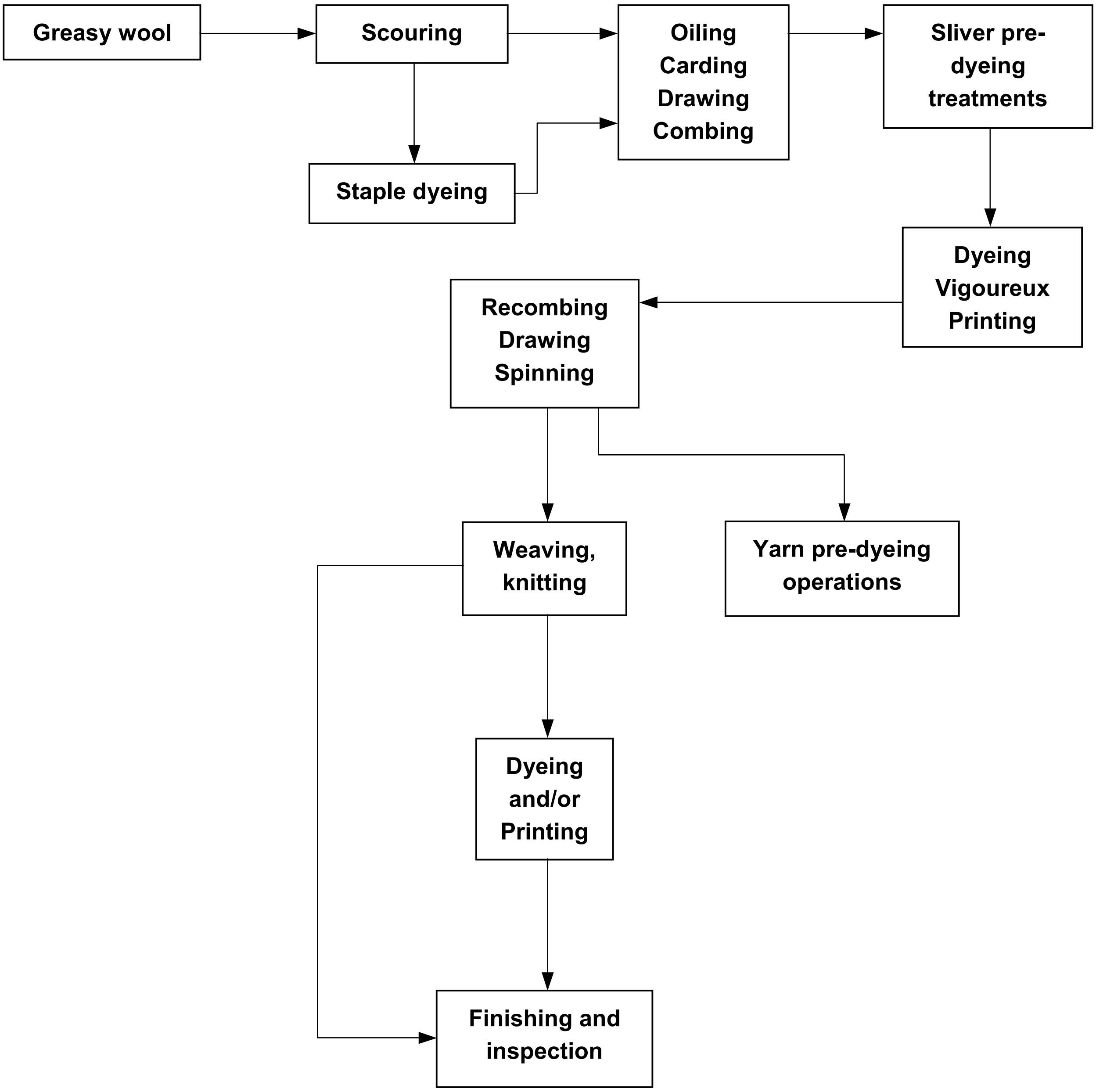
The textile finishing cycle:



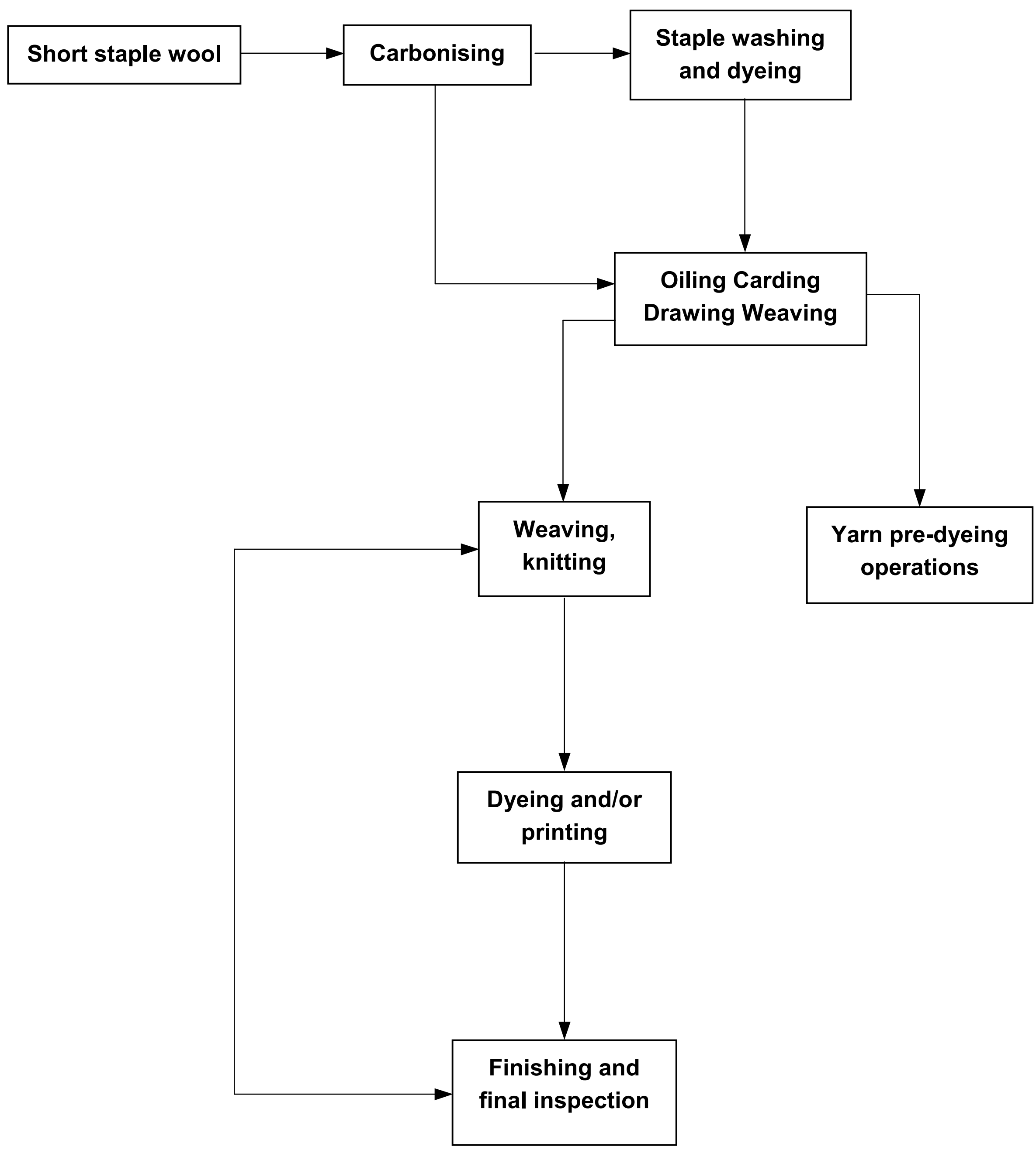
Wool finishing cycles

The sequence of the treatments undergone by wool fibres in various forms (staple, sliver, yarn, woven and knitted fabric) varies according to the modification process of the fibre structure, according to the type of processing system used and according to the experience of the operator (these criteria are valid for all fibres).
Therefore the wool processing cycle can vary according to several schemes. An example is shown in the following.

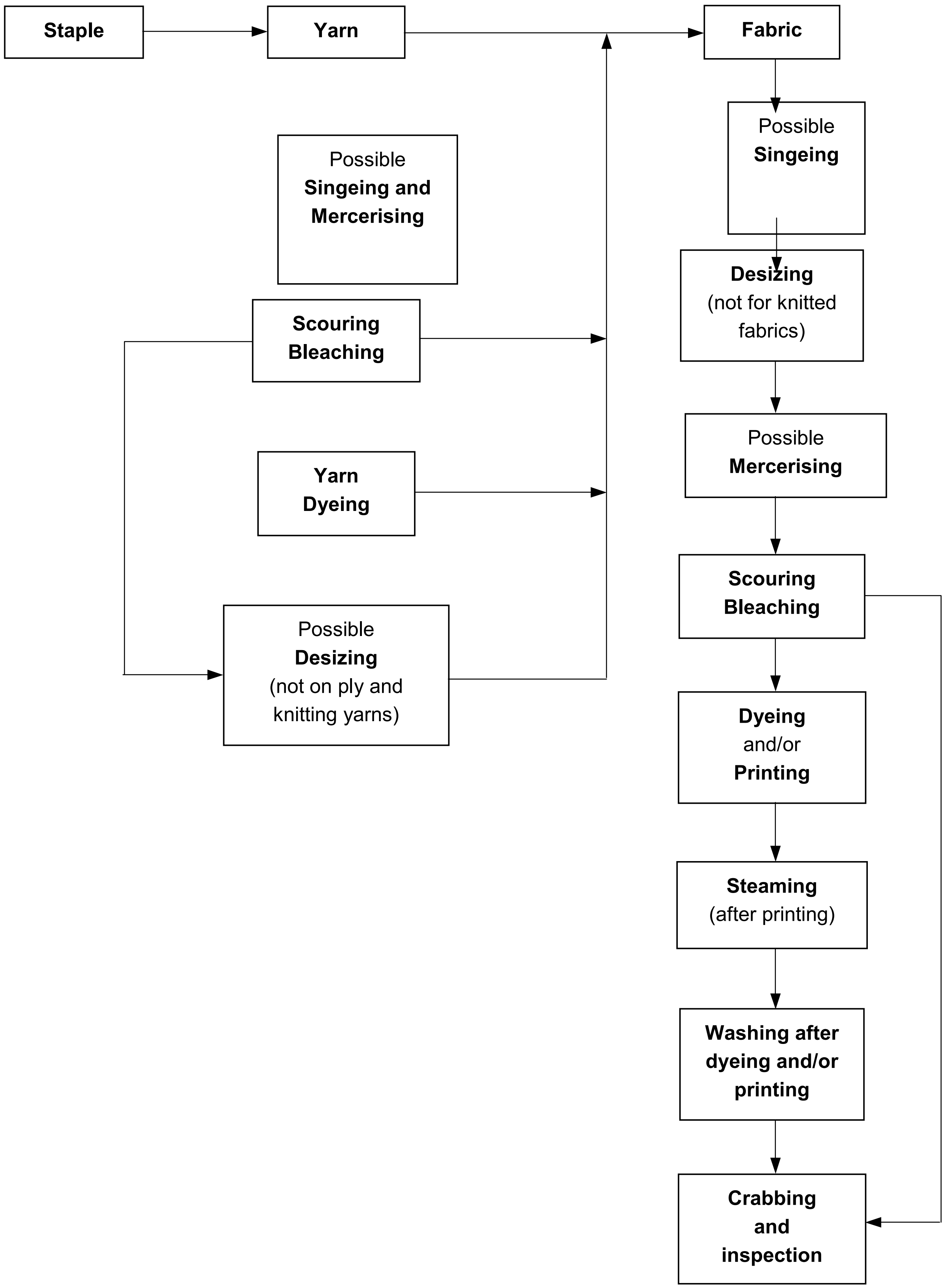
Worsted finishing cycle:



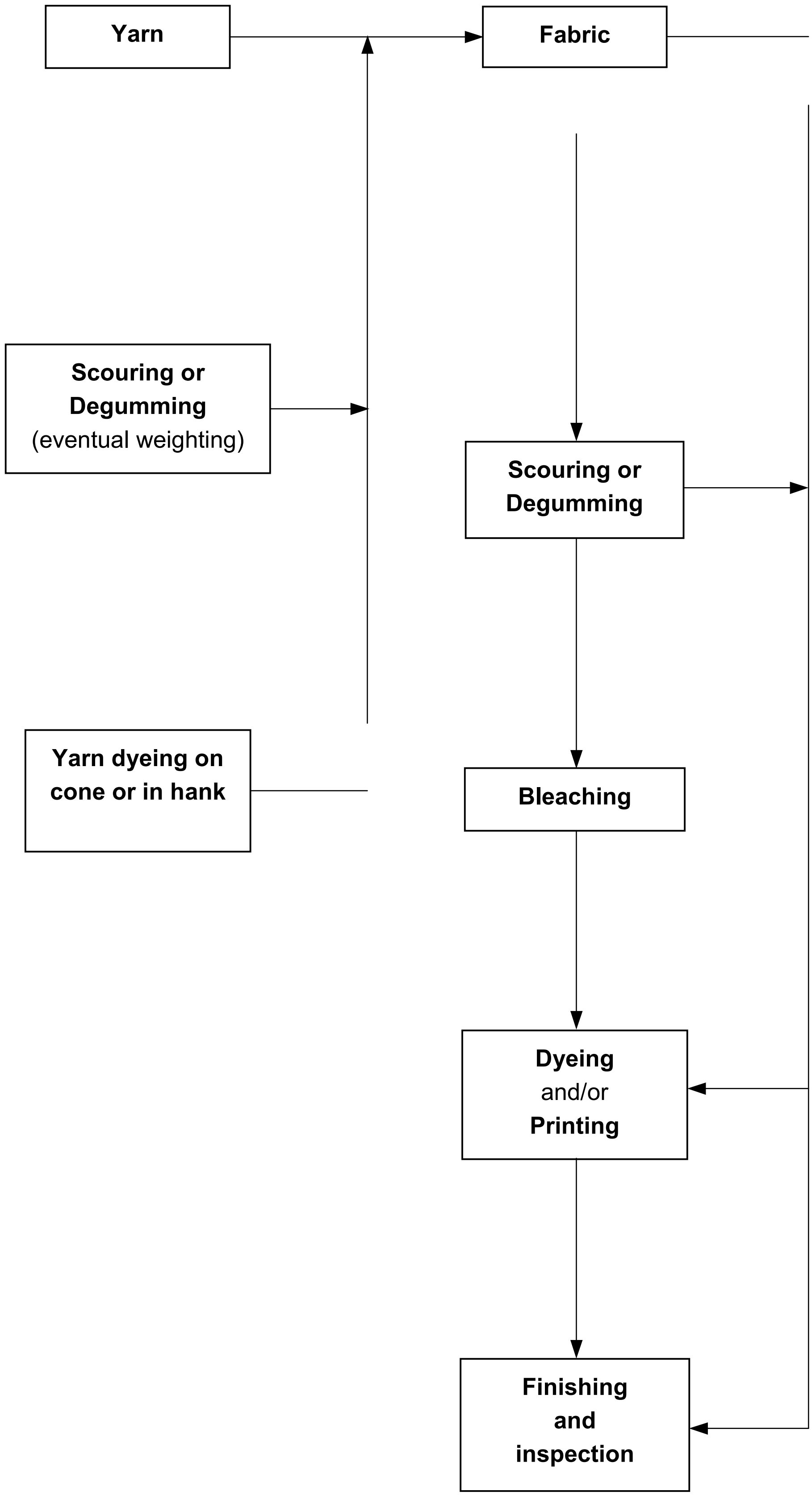
Woollen finishing cycle:



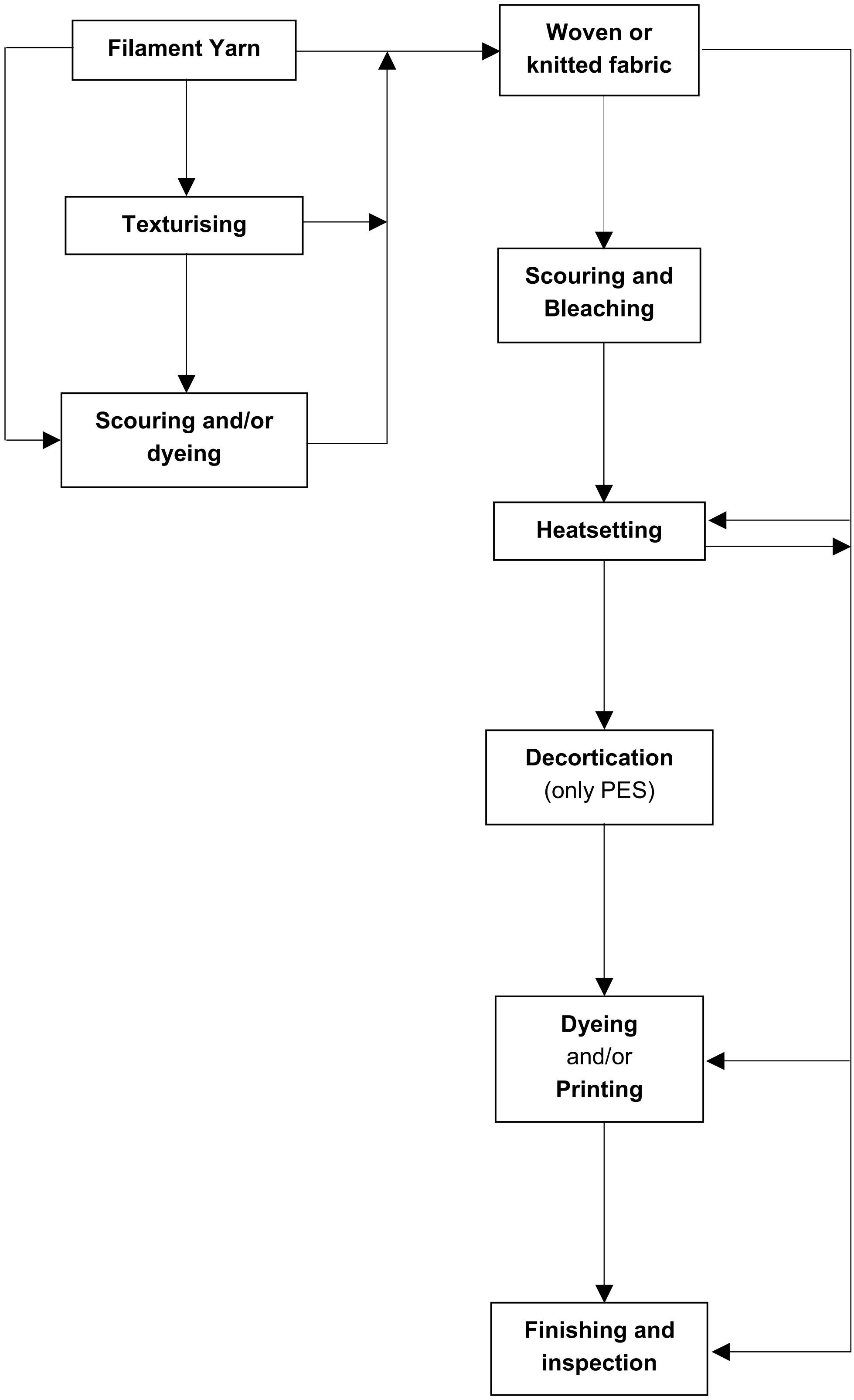
Cotton finishing cycle



Silk finishing cycle



Man-made fibres finishing cycles



PRE-DYEING TREATMENTS

The pre-dyeing stage includes a series of operations that prepare the textile product for subsequent finishing treatments such as dyeing, printing and finishing.
These operations vary according to the type of fibre on which they have to be carried out, to the structure of the textile product (staple, top, sliver, yarn, fabric) and also depend on the subsequent treatments to be carried out, which may change according to various factors such as market demands, customer requirements, staff experience and availability of machines.
The pre-dyeing stage includes for example **singeing, desizing, mercerizing, scouring and bleaching.** Each process varies according to the processing conditions and to the above-mentioned specific situations.
Some of these processes (for example bleaching and mercerizing) can be considered either preliminary operations or finishing treatments; this depends on the type of the downstream processes to be carried out on yarns or fabrics.

Singeing

This treatment has the purpose of eliminating the fluff protruding from the fabric, in order to make more evident and visible the fabric weave and to yield a smooth surface, besides ensuring higher soil-resistance and lower tendency to pilling.
This operation is generally carried out on loomstate (grey) fabric pieces and its residues are removed through a subsequent scouring process.
Singeing is seldom carried out on knitted fabrics, but quite frequently on woven fabrics.
A preventive brushing prepares the fabric to singeing, by eliminating fluff and impurities.
The singeing tool is an oxidizing flame which does not leave any sooty residue on the fibre.
The latest singeing machines operate with a gas/air ratio controlled by a motorized mixer, in order to assure a perfect combustion; moreover a pyrometer for the control of fabric temperature adjusts the singeing effect by varying flame height or fabric running speed.
The flame can assume different positions:

- Tangential to the fabric: in this way a superficial hair singeing with the removal of protruding fibre is obtained. This method is ideally suited for the processing of very light and delicate fabrics;
- Perpendicular to the fabric which runs on a water-cooled roller: the fabric remains relatively cold, thanks to the fact that its back runs in contact with the cooled roller. This method is ideally suited for processing fabrics in made-made and thermoplastic fibres;
- Perpendicular to the fabric, before the cooled roller: in this position, the highest singeing efficiency can be obtained. This method is best suited to fabrics in natural fibres.
  The fabric running speed can range from 60 to 120 m/minute.

A suction and damping unit ensures the removal of the fumes generated during the process.
As alternative to the classic singeing operation, an enzymatic treatment with cellulase enzyme (bio-polishing) can be carried out, to remove superficial fluff and dead fibrils. Improvements in handle, drape and lustre can be obtained by combining the cellulose treatment with a mild mechanical action.

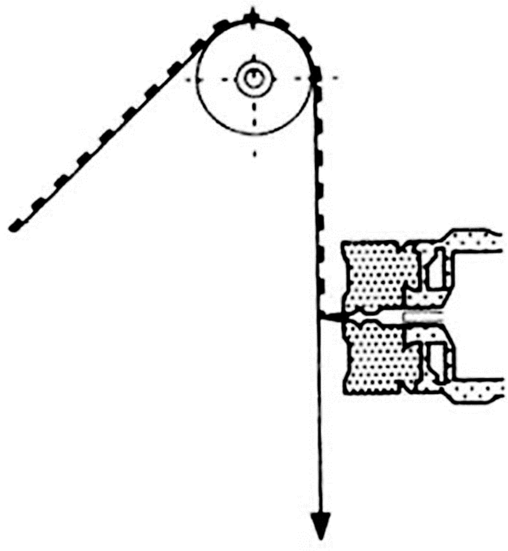


Fig. 1 Scheme of fabric singeing machine with flame perpendicular to fabric

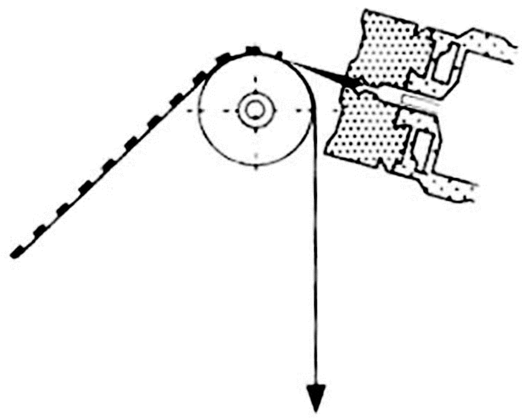


Fig. 2 Scheme of fabric singeing machine with flame tangential to fabric

Desizing

This treatment is carried out on woven fabrics to remove the sizing substance from the warp. The size must be totally eliminated since the fabric must absorb the liquor of subsequent processes homogeneously.
Since amylaceous sizes are generally used for cotton yarns, it is possible to apply amylolytic enzymes *(enzymatic desizing*), which carry out a biological degradation process of the starch, transforming it into soluble by-products which can be then eliminated by washing. The enzymatic process depends on the quantity of enzyme molecules per gram of fabric, while the thermal stability of the enzyme depends on the bacteria strain from which it originates. The amylases only react with starch molecules and do not affect the other glucose polymer (cellulose), since they attack the 1.4 alpha-glucoside bond of starch and not the 1.4 beta-glucoside bond of cellulose.
This reaction makes the use of amylases profitable (when applying starchy sizes) compared to other desizing agents such as alkali and oxidising agents *(oxidising desizing*), which attack both starch and cellulose.
The oxidising desizing process is used to remove non-starchy sizes that do not dissolve in water, or to eliminate starchy sizes combined with polyvinyl alcohol (this treatment is carried out before the singeing process).
This last treatment requires accurately controlled operating conditions to solubilise only sizes and avoid any possible fibre degradation. Enzymatic desizing can be carried out in discontinuous systems *(jigger*), but semi-continuous or continuous techniques are more frequent after the pad-batch wetting of the fabric. The most frequently used processes are *pad-roll* and *pad-steam*.
If the size is water-soluble, it can be eliminated by hot washing.

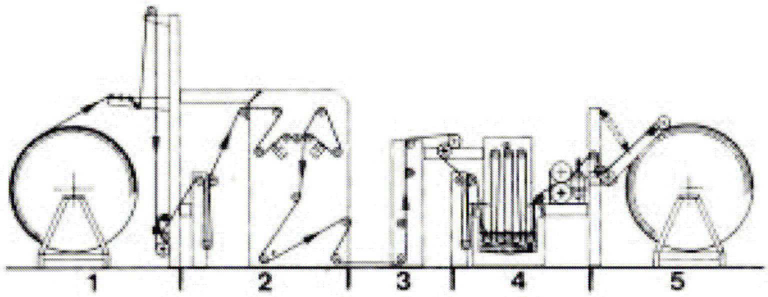


Fig. 3 Continuous line for singeing, brushing, impregnation, enzymatic desizing and preliminary cold bleaching at small, medium and high speed (up to 200 m/min) on woven fabrics in cotton, flax and natural fibres pure or blended with man-made fibres

Scouring

On cotton fibres, this treatment aims at removing fatty and pectic substances, softening the husks and preparing the material to absorb the subsequent treatment agents.
Scouring is usually carried out in soft water additivated with textile auxiliaries such as absorbing agents, detergents, emulsifying agents, caustic soda and/or sodium carbonate and sequestering agents.
Alkalis make the fibre swell and enhance the action of surfactants. This treatment can be carried out on sliver, yarn and fabric.
Instead of the traditional scouring process, it is also possible to carry out an enzymatic scouring process (bioscouring) to remove non-cellulosic material from cotton fibres, to make them more easily wettable and capable of absorbing subsequent finishing baths.
The scouring of pure silk, named degumming process, is used to remove sericin from fibroin floss. Sericin is the gummy element which keeps together the fibroin floss and gives the silk a hard hand

and dull appearance. It is carried out on yarn for yarn-dyed fabrics, on piece-dyed fabric or on printing substrates. The treatment, which causes a loss of weight ranging between 24 and 28%, gives the degummed silk a lustrous appearance and a soft hand; the treatment is carried out with soapy solutions or with buffer dissolving agents. It is also possible to use enzymes (protease), which hydrolyzes sericin. Recently, a treatment with H_2O at 120°C has also been successfully applied, especially on yarns.
On wool, the scouring process removes oils and dirt accumulated during upstream processing steps and can be carried out on slivers, yarns and fabrics with solutions containing sodium carbonate with soap or ammonia, or anionic and non-ionic surfactants, which carry out a less intense washing but do not damage the fibres.
The scouring process applied to man-made fibres removes oils, lubricants, anti-static substances, dust, dirt and can be carried out both on yarns and fabrics (in case that warp yarns have been sized, the treatment is called desizing). It is carried out by means of surfactants, detergents and emulsifying agents.
Scouring is usually carried out by means of continuous or discontinuous systems, with the same machines used for downstream treatments; temperature, processing time, pH, concentration of reagents, depend on the fibre and on the machine used.
Incomplete scouring processes usually originate dyeing and printing defects due to different hydrophility and dye affinity of the material.

Bleaching

Bleaching treatments are applied to eliminate any impurity and obtain a pure white tone, to prepare substrates for dyes or prints with low pattern coverage and to strip undesired tone variations.
Bleaching agents mainly used for cellulosic fibres are sodium hypochlorite and hydrogen peroxide. They both require the addition of sodium hydroxide in the bleaching liquor, which makes it alkaline by favouring the formation of the bleaching ion, which in the first case is the hypochlorite ion and in the second one is the perhydroxyl ion.
When using hypochlorite, the pH must range between 9 and 11 and the temperature must not exceed 30° C. In fact, as far as the pH is concerned, pH values below 4 give rise to the formation of chlorine, while pH values ranging between 4 and 9 give rise to the formation of hypochlorous acid: these chemical substances damage the fibre and do not perform a bleaching action. After bleaching with hypochlorite, it is necessary to carry out an antichlor treatment. Fibres must be treated with hydrogen peroxide, which completely removes chlorine and avoids the formation of chloramines which, in drying machines, could generate HCl, dangerous for cellulose.
With hydrogen peroxide in the presence of alkali, seed husks can be eliminated and the scouring in autoclave can therefore be avoided.
The optimum temperature ranges between 80° and 90°C and the pH between 10.7 and 10.9.
Hydrogen peroxide at a concentration of 1-2 vol can be used also for silk after degumming, with a pH of 8–9, at 70-80°C for 1-2 hours.
On wool, it is possible to improve whiteness with a bleaching process using hydrogen peroxide, with a vol. range of 1 to 3, stabilised with pyrophosphate with a pH value between 8 and 9 at a temperature of 45-50° C for a time which can vary from 30 minutes to 3-4 hours. In alternative, it is possible to carry out a treatment at a pH value of 3-4, in acid environment for HCOOH at ambient temperature; in this case, the formic acid reacts with peroxide, generating performic acid, which carries out the bleaching action. This method slightly damages the wool but gives good results.
From an ecological point of view, hydrogen peroxide is more suitable than hypochlorite since it has a lower impact on the environment and simplifies the purification of the effluents.
It is recommended to add sequestering agents to the bleaching baths.
Another bleaching agent used in textile processing is sodium chloride (suitable for man-made fibres) that takes advantage of the oxidising action of chlorine dioxide, generated as a result of the

hot acidification of a solution of this salt. However chlorine dioxide is a toxic substance and attacks stainless steels; therefore it is necessary to operate in hermetically closed machines made of resistant materials, such as stoneware. equipped with suction systems.
Bleaching operations can be carried out on yarns, knitted and woven fabrics with discontinuous process in circulating liquor machines (*autoclaves, jiggers, winches, air-jets, overflows*), as well as with semi-continuous *(pad-batch, pad-roll*) and with continuous processes. Manufacturers offer for example continuous rope bleaching lines for large and small-size lots, which are able to carry out scouring and hypochlorite/peroxide bleaching on knitted and woven fabrics in cotton and linen.

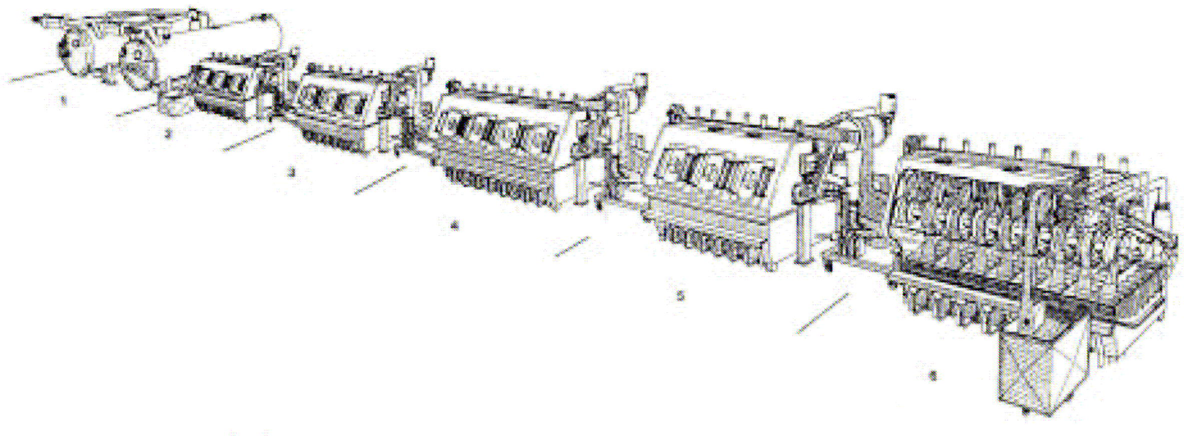


Fig.4 Continuous rope bleaching line

1.Desizing and scouring under pressure 2.Scouring baths 3.Bleaching with hypochlorite at 20/30°C 4.Scouring baths 5. Bleaching at 85°C 6.Scouring baths

Continuous bleaching can be carried out also on knitted fabrics by using a J-box. The products to be used on the fabric are applied by means of suitably positioned padding mangles; the fabric is introduced in the machine, where it remains for the time necessary to complete the bleaching process.
Temperature, speed, pressure and pH are controlled automatically.
It is also possible to carry out optical bleaching using substances that do not perform a chemical action on the fibre but obtain a whitening effect by means of an optical compensation process of physical nature. In fact these substances release a blue light compensating white and grey and produce a lily- white effect. For example, an optical bleaching on wool can be carried out after chemical bleaching using 0,2-0,6 g/l of optical whitening agent at pH 4-5 by means of acetic acid, at a temperature of 50-60°C for 30 minutes.

Mercerizing

This is a typical treatment for cotton yarns and fabrics which improves the fabric lustre and hydrophily, ensures a covering effect for dead cotton, improves dimensional stability and dye yield.
This treatment is carried out using caustic soda, which determines the contraction and swelling of the fibres; these become translucent and increase their tensile strength, but reduce their flexing resistance and torsional strength. The bean-like section of the fibre becomes at first elliptic and then circular, thus allowing a better light reflection with consequent increase of lustre.
The treatment is usually carried out under tension, with caustic soda at 28°-30° Bé (approx. 270-330 g/l).
If the concentration is lower than 24° Bé, the treatment is called *causticization* and aims at enhancing the dyeability of the fabric.
The liquor temperature usually ranges between 15 and 20° C and its uniform absorption is assured by adding mercerizing wetting agents, stable in alkaline environment. Once the operation has been carried out, alkalinity must immediately be neutralised by means of diluted acid solutions.
From a chemical point of view, alkalicellulose is the first material to form; the next material, which forms after repeated washing in water, is hydrocellulose, which is more reactive than natural cellulose.
Cotton wetting entails shrinkage of the material, which therefore must be kept under tension to avoid a wrinkled and woolly appearance.
Mercerization is carried out on yarns, woven fabrics and open or tubular knits.
As far as yarns are concerned, before mercerization in special machines they undergo a singeing treatment to remove the fluff, which could otherwise prevent the perfect reflection of light after mercerizing. There are two different types of machines to be used for woven fabrics: chain machines and cylinder machines.
Chain mercerizing machine: this machine permits to achieve optimum performances in terms of fibre brightness, thanks to an excellent tension control. However these machines run at slow speed and are not flexible in conforming to fabric width variations.
Cylinder mercerizing machine: this machine is more compact and faster than the chain machine; however it does not allow the contraction of the warp, because of fabric passage on the cylinders.
The shrinkage of the weft yarns is also hindered by the tension produced by the simultaneous action of the cylinders and by fabric wetting. Cylinder mercerizing machines are also used for plain knitted fabrics.
The latest machines are generally provided with a circuit for the recycling of the mercerization bath and with an automatic adjuster of liquor density, which permits a perfect reproducibility of results on large-size lots, even after some time.
The mercerizing process can also be carried out on tubular knitted goods: after wetting, the fabric is left to react in a padding mangle. The withdrawal of the fabric in width direction is controlled by means of an adjustable ring spreader, while fabric shrinkage in length direction is controlled by "slowing down" the fabric before the final squeezing. The sodium hydroxide concentration is brought down to approximately 4° Bé by means of circular showers. The fabric is then washed, neutralized and rinsed.
Another well-proven mercerizing agent is liquid ammonia, which has to be applied for very short times (about half second). There are very few plants using this technology, due to the difficulties connected with the use of liquid NH_3 (toxicity, formation of explosive blends with air), and to very strict regulations for the welding of steel plates used to build these machines, that have to operate at very high pressures, since the boiling point of ammonia is usually –33°C.

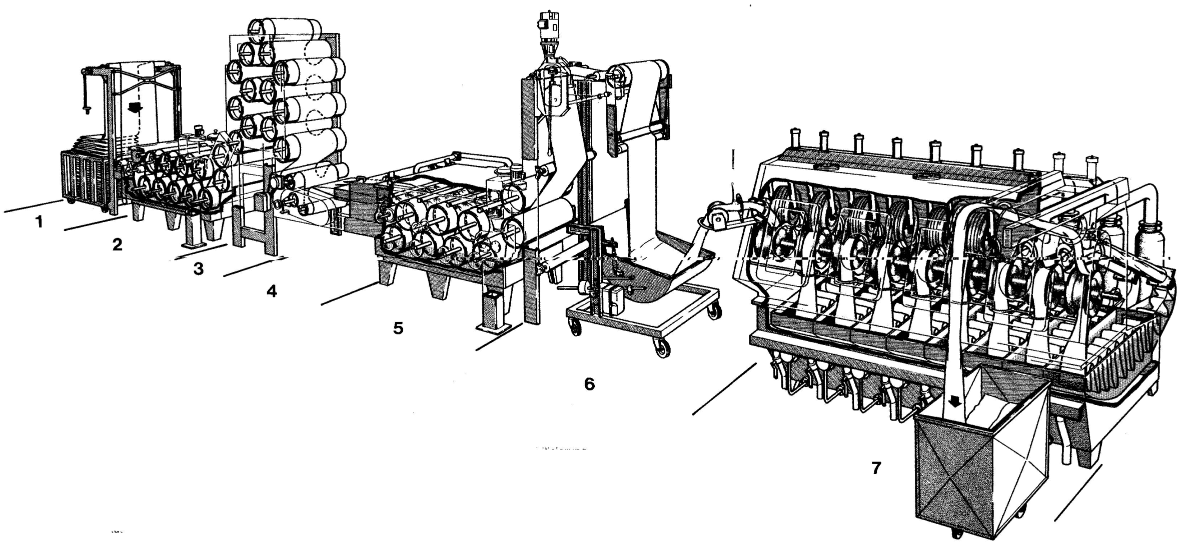


Fig. 5 Continuous mercerizing and bleaching line for tubular knitted fabrics

1. feed 2. wetting with $NaOH_3$, exposure 4. spreader 5. stabilizer 6. exit 7. neutralization and bleaching

Recently also continuous mercerizing cycles and machines for combined mercerizing/bleaching processes for tubular knitted goods have been developed. These consist of a continuous open-width mercerisation line for tubular knits and of a continuous line for neutralization, peroxide bleaching and open-width scouring of the fabric.
These machines allow to carry out mercerizing and bleaching in a single passage, with considerable reduction of the processing costs.

Chlorination

This specific treatment applied to wool enhances its dimensional stability to shrinking; it can also be used as finishing or preparation process before dyeing or printing. Thanks to the reduction of the cuticle thickness with the consequent disappearing of scales (which are rounded off and made thinner), wool looses its felting capacity and therefore minimizes shrinkage (dimensional stability). The result is that a chlorinated wool garment can undergo repeated machine washing cycles (delicate cycle).
The process can be carried out at any stage of the fibre processing; chlorinated wool is particularly lustrous and has higher dye affinity.
From an operational point of view, the best results can be obtained with the combination of two different and complementary treatments: an oxidising treatment, followed by a special treatment with cationic resins.
The first treatment is the traditional chlorination process, carried out using:
- NaClO in presence of strong inorganic acids (sulphuric acid)
- Cl_2 in gaseous form
Chlorine organic salts (sodium salt of dichloroisocyanuric acid) which, in acid solution, releases chlorine.
The second treatment is carried out by applying special resins enhancing the anti-felting effect (PA–epichlorohydrin or polysiloxane-based cationic resins).
An antichlor treatment with $NaHSO_3$ must be carried out subsequently to eliminate any residue of Cl_2 that might remain on fibres.
New treatments to be carried out on tops or fabrics (plasma treatment) are now being studied as an alternative to chlorination.
Process and machines used: circulating liquor apparatus are used for tops; autoclaves are preferred for yarn packages, while overflow systems are used for woven or knitted fabrics.

Carbonizing

When we process finest and long staple wools for the production of worsted yarns, foreign substances (mainly of cellulosic origin) are removed almost completely by the combing machine. The combed sliver contains therefore very small quantities of foreign particles, which do not affect the subsequent treatments, and above all the dyeing process.
A different approach must be however applied in the woollen cycle, where the quantity of contaminants requires a specific treatment with sulphuric acid, to avoid any possible problems during the dyeing process.
Carbonizing is also essential when the raw stock is mainly composed of rags or waste (dry carbonizing with gaseous HCl at 80°C). In fact, with this type of material the carbonizing process eliminates any vegetal residue in the staple after scouring; wool is not affected, due to its good resistance to the action of acids which, on the contrary, destroy cellulose owing to the strong dehydrating action of the acid, which causes a loss of weight that cannot be exactly evaluated in advance.
Carbonizing can be carried out also on staple fibres, yarns and fabrics. Washed and sometimes piece-dyed fabrics as well as grey fabrics can also be carbonized.
The operating conditions necessary for the carbonizing process are the following: the fibres are soaked with H_2SO_4 (2,5–4° Bé or 4–6%), squeezed by means of two cylinders and then dried in a stenter at 85–90°C for 30–60 minutes.
Hot air concentrates the acid by evaporation, as a result dehydrating and hydrolyzing the cellulosic component. Finally fibres are carefully washed to remove completely any residual acidity which

could affect the fibre and subsequent operations. A series of washing processes also includes a neutralisation treatment with sodium acetate.
During fabric processing, a dry beating process to remove the carbonized vegetal residues from the fabric texture precedes the washing phase.
Process and systems used: wetting vessels, squeezing cylinders, stenter, dry fulling unit.

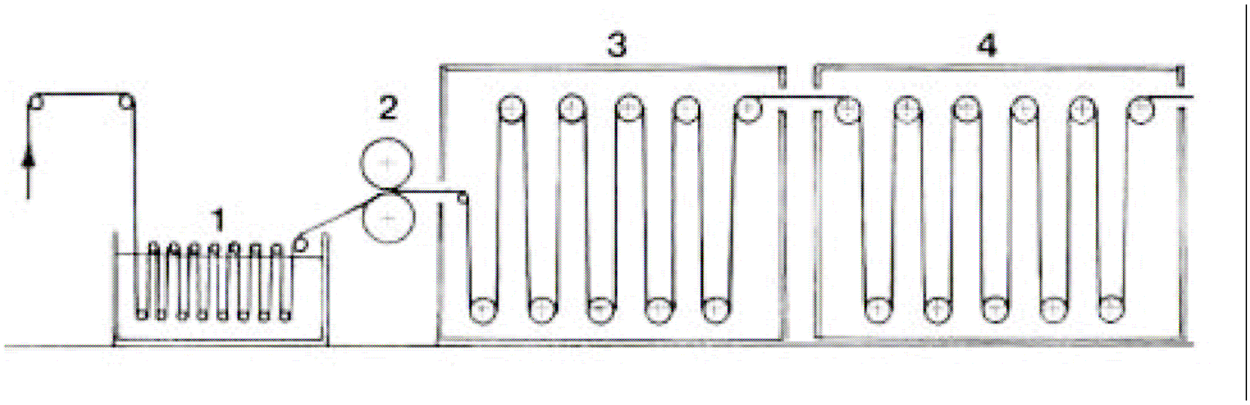


Fig. 6 Traditional fabric carbonizing line

1) wetting vessel; 2) squeezing unit;
3) dryer chamber; 4) carbonizing chamber

Solvent/water combined process

This process bases its efficacy on the fact that perchloroethylene, thanks to its low surface tension, can soak textile fibres deeper and faster than an aqueous solution.
On the contrary, since vegetal impurities contained in the fabric are highly hydrophilic, their affinity for the solvent is lower than the fabric; the solvent is contained only in the surface of vegetal particles. When the fabric soaked with solvent comes in contact with an aqueous solution of sulphuric acid, the aqueous solution cannot remove the solvent from wool and replace it. On the contrary, the aqueous solution is absorbed by vegetal hydrophilic particles. In practice, with this system vegetal impurities absorb the acid solution selectively and the acid carries out only a gentle action on wool.
The benefits of this process are lower pollution, considerable reduction of damage to wool and possibility of by-passing the acid removal step (or if necessary, this step is considerably easier and faster).

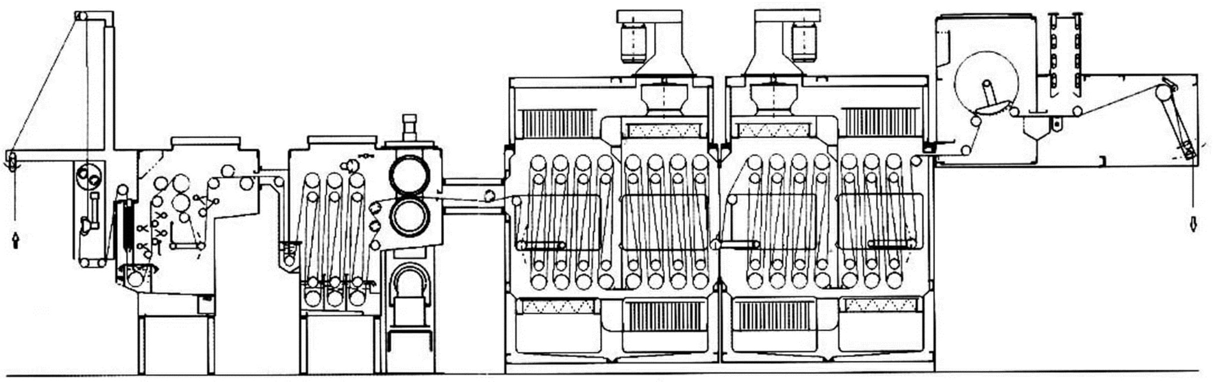


Fig. 7 Scheme of solvent carbonising line

Oiling

The oiling process aims at minimizing friction during the various operations that transform staple into yarn and then into fabric.
Operating conditions: staple is sprayed with oil emulsions in water stabilized with surfactants (favouring the subsequent elimination).

Fulling and washing-milling

During the traditional milling operation, fabrics of combed, carded or blended wool (non-scoured, scoured or carbonized and neutralized) at about 40°C are soaked and are subjected, in presence of special surfactants, to continuous pressure both in weft and warp direction. Under these conditions, wool fibres tend to felt, thus causing fabric shrinkage and subsequent dynamic compacting. After this operation, the material must be washed to remove dirty water and the chemicals used.
Temperature and mechanical stress must be carefully controlled during all the processing steps; the operation is completed when the desired shrinkage degree has been obtained. Obviously it is necessary to avoid rope wrinkling or irregular shrinkage on the fabric.
When the process is carried out with older fulling units, the ropes are sewn before loading into a tubular structure to favour the wrinkle movement and avoid irregular tensions on both selvedges; in this process, an air pocket is formed inside the "cylinder" of wet material, thus favouring the wrinkle movement. The percentage shrinkage in warp direction (lengthwise) is controlled from the beginning by means of markers positioned in the centre of the piece in warp direction, at one meter distance.
In newly designed machines, the fabric milling process is often combined with a washing process, which sometimes is a quick washing process.
Here are some components which usually make up a milling machine:
Jaws: vertical parallel steel plates, positioned in the front part of the machine, that make the fabric shrink in weft direction by squeezing the fabric.
Pressure cylinders: adjustable pressure cylinders that make the fabric shrink in weft direction and push the fabric inside the box.
Box: square section tube, where the fabric is packed, slowed down by the adjustable plate. In this section, the fabric shrinks in warp direction.
Plate: hinged plate on top of the box; it can be lowered by reducing progressively its section, slowing down the fabric.
Washing-milling machines also include:
Squeezing cylinders: to favour the change of the washing liquor.
Vessel: placed below the squeezing cylinders to collect polluted water and drain it. When the vessel is open, water is poured directly into the liquor.
Many machine manufacturers have studied custom-made solutions to enhance the milling and/or washing effect or to increase machine flexibility and improve its output capacity. These machines can generally process fabrics, whose weight ranges between 80 and 800-1200 g/linear meter. The following examples show some of these solutions:

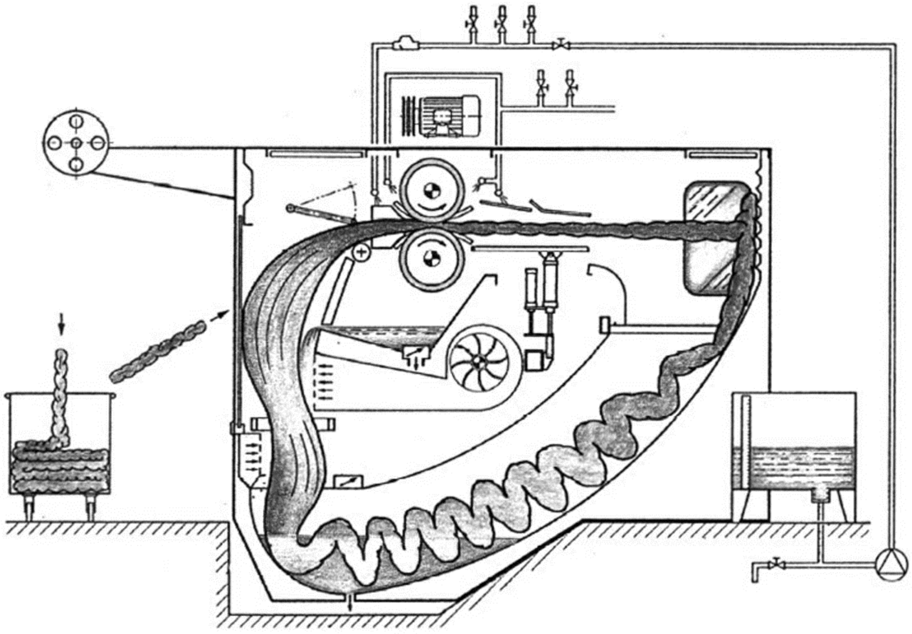


Fig.s 8-13 Schemes of milling machines in different operating phases

Milling phase: air jets move the wrinkles of the incoming rope (some machines can also do this on the delivery side); the plate is lowered and the jaws are closed. Machines with this particular structure can run at a maximum speed of 250-300 m/min (Fig. 8).

Delicate washing phase: the air jets move the rope wrinkles; the plate is lifted up, while the liquor is uninterruptedly fed on the fabric. This type of machine can run at a maximum speed of 200-220 m/min. (Fig. 9).

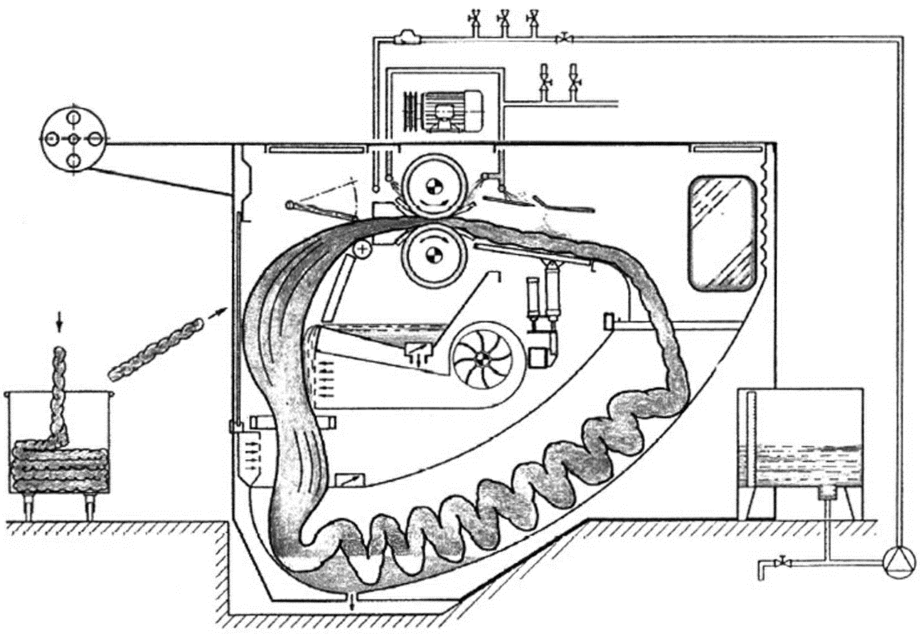


Fig. 9

Fast washing phase: the air jets can remain open. The fabric, drenched with liquor, moves at a speed ranging between 400 and 600 m/min with open plate and runs into the grid. Beating, combined with high speed, causes a slight felting on the surface and the yarn swells, which results in hiding the comb marks (Fig. 10).

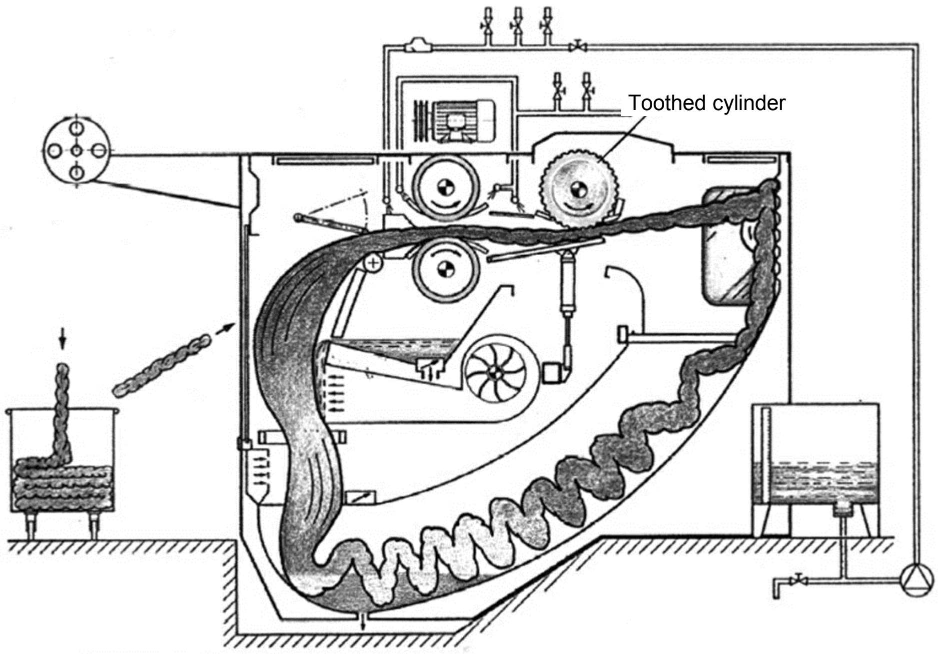


Fig. 10

Alternatively, the fabric can be taken up by a toothed cylinder helped by the lower part of the plate, thus increasing the milling effect (Fig. 11).

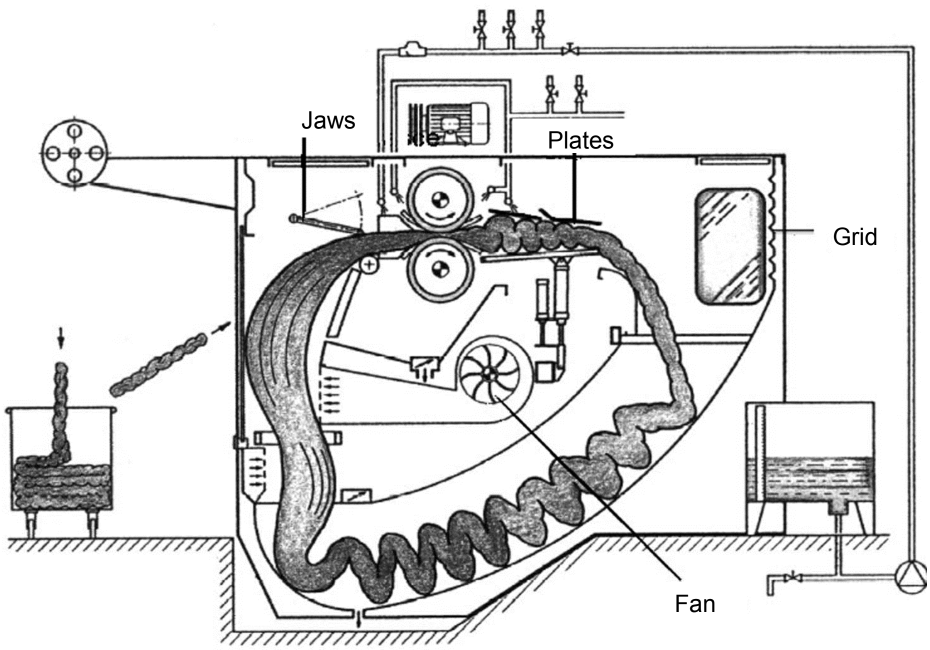


Fig. 11

Some machine manufacturers have preferred a solution with two upper cylinders for feeding the fabric and a lower rubber cylinder with a rough surface (Fig. 12).
Split-flow milling and washing phases*: on some machines it is possible to carry out one or two treatments on fabrics of different weight.*

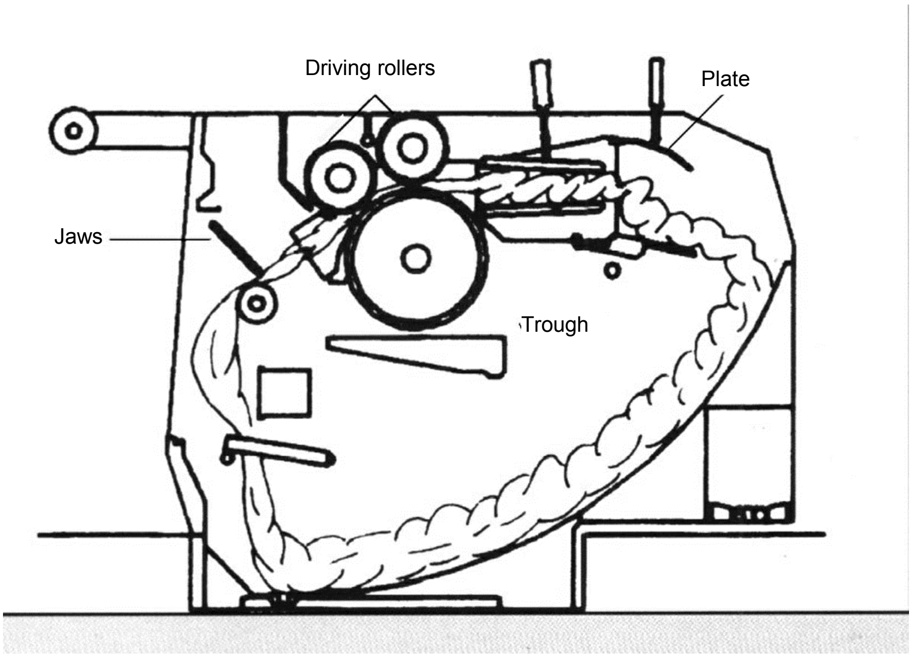
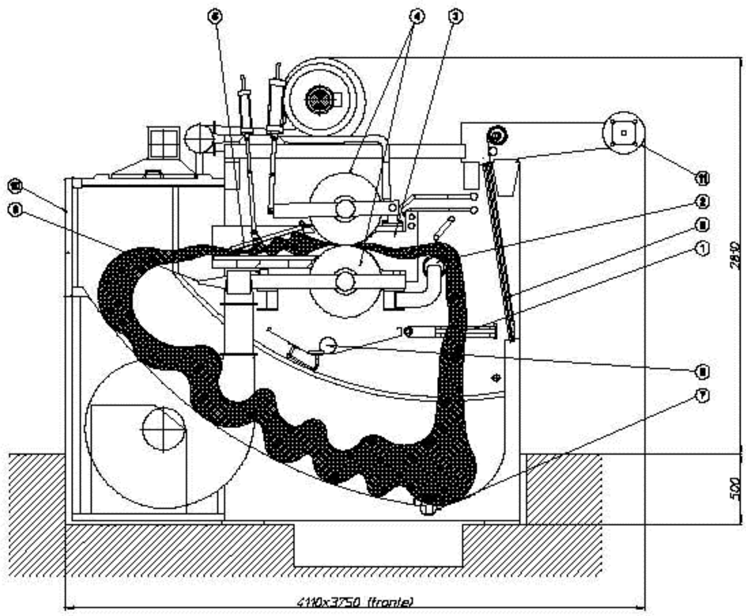


Fig. 12

The shrinkage of each fabric and the machine settings can be selectively and individually controlled. In these machines, the fabric is exposed to powerful air jets while falling down from the milling box; this changes continuously the rope position.



1. *Fabric guide*
2. *Fabric driving roller*
3. *Jaws*
4. *Rollers of steel or seasoned oak*
5. *Plate*
6. *Air jet*
7. *Vat drain*
8. *Trough drain*
9. *Front glass door*
10. *Rear door*
11. *Fabric delivery roller*

Fig. 13

On these machines too, the expertize of machine manufacturers and the application of the latest electronics have allowed the introduction of some devices that increase the output capacity and permit more accurate controls, ensuring excellent repeatability.
Some of these new devices are for example: fabric-skid control devices; independent split-duct milling machines that allow to process different fabrics in different conditions with consequently different results; non-stop seam position detector for each separated duct, with individual stop of each single rope; front positioning of the seams of all ropes when the machine stops.

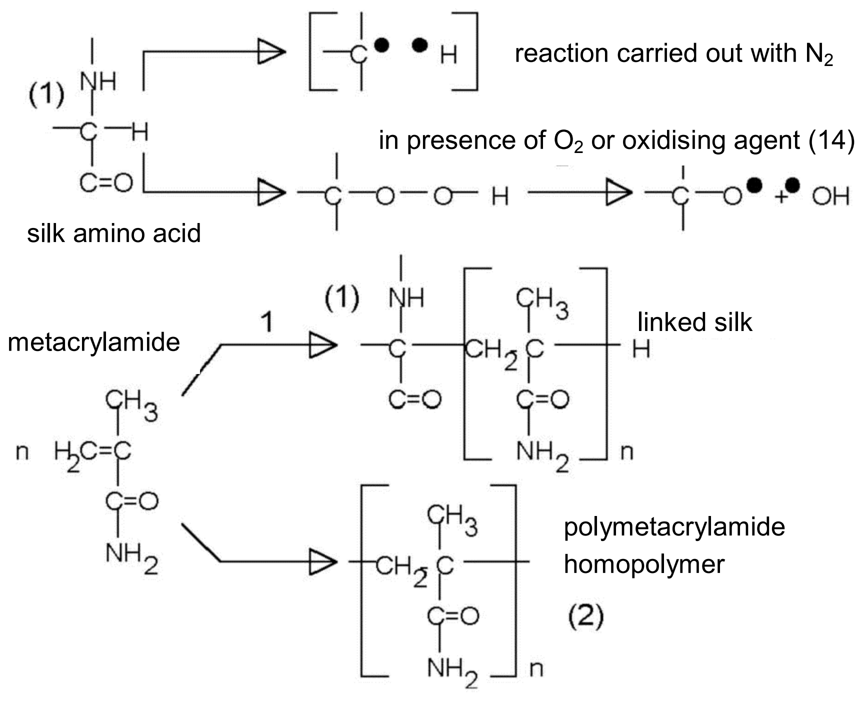
Silk weighting

The weighting process is carried out to increase the silk weight, to provide a fuller handle, more lustre and bulk, and to make the fibre suitable for the manufacturing of fabrics to be used, for example, for ties. The weight increase is expressed as percentage weighting over or under the parity. Parity weighting means that the fibre regains the original weight it had before the degumming process:

Percentage weighting = (weight after weighting – raw weight) x 100/ raw weight

There are many types of weighting; till some years ago, a few mills still carried out mineral weighting, but now this process has been abandoned definitively. Today, the most frequently applied type of weighting is synthetic weighting (or chemical linking).

Synthetic weighting
Chemical principle for weighting with metacrylamide:
The monomer used for synthetic weighting is often derived from acrylic or metacrylic acid. The silk weighting with acrylonitrile and methylmetacrylate has been studied and described thoroughly; in this process, starters are formed by a redox system based on iron salts (Fe++) and hydrogen peroxide, persulphates and other substances.



Scheme of the initial linking reaction through formation of radicals

The weighting reaction can occur on the alpha carbon atom of the amino acids which make up fibroin (1), or on lateral chains, such as for example the methyl group of alanine.
At the same time, we can have a competing weighting reaction with the metacrylamide homopolymerisation, as shown in diagram (2). Once formed, these homopolymers cause a significant hardening of silk and, even if not bonded through covalence to the fibre, cannot be eliminated with further repeated washing.
Basically the real weighting process is carried out by means of a MAA- (meta-acryl-amide)- based resin. Good swelling and a high-lustre finish of the fibre can be obtained with this method, but the quality of the handle achieved is poorer than the quality obtained with mineral weighting also the dye affinity is of inferior quality, even if the handle is usually harder, thanks to good fibre swelling.
To achieve parity weighting, it is necessary to use 50% of MAA calculated on the total fabric weight, 3.5% of ammonium persulphate (catalyst) calculated on the resin weight, 2 ml/l of formic acid and 0,2 g/l of nonionic surfactants. Starting from 40°C, the temperature must be brought to 80°C in 20 minutesand kept at this level for 60 minutes. The temperature is then decreased to 60° and the liquor is drained; after 10 minute washing with 2 g/l of soap at 80° C, silk is finally rinsed.
Now, more and more frequently milling facilities tend to carry out weighting operations with different unsaturated monomers which have different performance and are used in limited quantities; these unsaturated monomers work according to the same weighting principle, but give to silk unique effects and distinctive characteristics of dimensional stability and crease-proof properties. We indicate below some examples of monomers and catalysts used:

Vinyl monomer	**Formula**	**Starter**
-Methylmetacrylate (MMA)	$CH_2 =C(CH_3)CO_2 CH_3$	1-KPS, APS 2-TBB 3-Syst. metal redox 4-Syst. non-metal redox 5-Syst. complex transf. 6-Irradiation
-Metacrylamide (MMA)	$CH_2=C(CH_3)CONH_2$ 6-Irradiation	1-KPS, APS
-Styrene (St)-2-Hydroxyethyl--metacrylate (HEMA)	$CH_2=CH\text{-}C_6H_5$ $CH_2=C(CH_3)CO_2CH_2\ CH_2OH$	1-KPS 1-APS
-Metacrylonitrile (MAN)	$CH_2=C(CH_2)CN$	1-NaPS
-N(n-Butoxymethyl) - metacrylamide (nBMAA)	$CH_2=C(CH_3)CONH(CH_2\ OC_4H_9)$	1-APS
-Ethoxyethyl-metacrylate (ETMA)	$CH_2=C(CH_3)CO_2CH_2\ CH_2OC_2H_5$	1-APS
-Acrylamide (AA)	$CH_2=CHCONH_2$	3-Syst. metal redox
-N,N'-Methylenbis acrylamide (N,N'-MBA)	$(CH_2=CHCONH)_2CH_2$	3-Syst. metal redox
-Ethyl-metacrylate (EMA)	$CH_2=C(CH_3)CO_2C_2H_{5\ 5}$	6-Irradiation
-Buthyl-metacrylate (BMA)	$CH_2=C(CH_3)CO_2C_4H_{9\ 9}$	6-Irradiation 1-KPS

Vinyl monomers used for copolymer linking on silk fibres

1) KPS = potassium persulphate; APS = ammonium persulphate; NaPS sodium persulphate.
2) TBB = tri-n-butylborane.
3) Vanadium (V); Cerium (4); Chromium (VI); Thallium (III); Manganese (III)-oxalic acid; Complexes of manganese acetyl acetonate (III), Vo (II), Co (III).
4) Hydrogen peroxide-sodium thiosulphate; Peroxidiphosphate-thiourea; potassium peroxidiphosphate; Bromate-thiourea; Potassium peroxidiphosphate-fructose; Permanganate-oxalic acid.
5) Lutidine-bromine; Isoquinoline-sulphur dioxide.
6) X Rays.

Heat setting

This operation is a must for fabrics in man-made fibres (PES, PA, elastomers), triacetate and partly PAC fibres (setting), since it grants excellent dimensional stability and crease-proof properties, which are maintained till fabric exposure (by air blowing) to temperatures exceeding heat setting point (after being treated with water at a temperature above the second order glass transition temperature, i.e. 80-85°C for acrylics).
Heat setting is carried out on loomstate fabrics (scarcely applied), on scoured fabrics (frequently applied) and on dyed fabrics (rarely applied).
This process produces excellent dimensional stability and good crease-proof properties.
As far as operating conditions are concerned, the fabric must be treated at accurately controlled moisture and temperature conditions.

Fibre	**Min T.°C**	**Max T.°C**	**Time (in seconds)**
Polyester (PES)	170	210	15-50
Polyamide PA 6.6	170	210	15-40
Polyamide PA 6	160	180	15-40
Triacetate	160	180	15-40
Acrylic (PAC)	160	180-200	15-40
Elastomers	170	180-200	15-40

Machines used: stenters.
Fluctuating temperatures inside the stenter cause a consistent variation of crystallinity in the fibre structure, which leads to a different dye affinity.
The moisture in the fibre produces soft hand, but variable moisture percentages in the different sections of the fabric give rise to the above mentioned defect (variable crystallinity).
Too low temperatures do not allow a good setting, while too high temperatures and too long setting times cause yellowing (PA and elastic fibres), stiff hand (acrylics), and loss of elasticity (elastic fibres).
The presence of combustion gas (NOx) produces a yellowing of the elastomers.
The heat setting process carried out before scouring can fix the stains on the fabric or make the scouring process more difficult, due to the modification of the lubricating products (cracking with emission of polluting gas).
Heat setting after dyeing could lead to the sublimation of disperse dyes (if not accurately selected).

Decortication (only for polyester)

This treatment is aimed at providing a silky-smooth hand to polyester fabrics (up to a few years ago, this process was also used to obtain microfilaments by increasing fibre fineness), a lustrous effect and an enhanced drape. The best results can be obtained with fabrics produced with coarser yarns.
The open-width decortication process can be carried out on jiggers or beam dyeing machines; rope decortication is performed on jet or overflow systems (batch systems). Decortication is carried out after scouring and heat setting; it is better to carry out a heat setting treatment also after the decortication process.
Operating conditions applied: the process is carried out at a temperature ranging from 90-95°C to 120-130°C for 20-35 minutes, with 30-50 g/l of NaOH at 36°Bé. Once the process has been completed, the fabric is washed and neutralised.
Processes and machines used for open-width process are: jiggers or beam dyeing machines (batch systems), or special tensionless open-width continuous machines.

Fig. 14 Continuous decortication line for PES

Treatments on elastane-blended fabrics

In the case of fabric containing elastane yarns, treatments depend on the chemical composition, which can be extremely variable.
As far as the fabrics containing segmented polyurethane fibres are concerned, the suggested treatments to be carried out are the following:

- relaxation
- heat setting
- scouring
- bleaching/dyeing/printing
- finishing

Relaxation: before carrying out any further treatment, it is recommended to relax woven or knitted goods to obtain a uniform shrinkage and avoid stitch distortion or fabric deformation, creases or wrinkles. The fabric relaxation is a decisive step to allow good shrinkage and to give excellent elasticity to the fabric, since fabric width on the loom is always higher than the finished width (owing to yarn tensioning on the loom). It enables shrinkage, thus favouring elasticity.

The best method is table steaming, but it is also possible to perform steaming at the entry of the stenter or to carry out a scouring with hot solvents or a relaxation in hot water with tensionless scouring; these techniques however give poorer stabilisation results and do not provide permanent crease resistance to textiles and fabrics.

Thermosetting: this process is indispensable to give the fabric an optimum dimensional stability. It is recommended to carry out a heat setting treatment before any further wet treatment, in order to avoid the formation of possible creases and folds. An optimum heat setting requires a temperature ranging between 180° and 200°C, which must be maintained constant for at least 45 minutes. An optimum heat setting also requires the use of an indirect air heating stenter,allowing more uniform temperatures and no-gas conditions to avoid fibre yellowing. The fabric is weighed at the entry of the stenter and then subjected to steaming. Since the fabric shrinks during the heat setting treatment, the fabric width on the stenter must exceed the desired width by 5-10%. An excessive heat setting could decolourize the fabric, while an insufficient heat setting will result in poor fabric stability.

Scouring: it is necessary to carefully consider the characteristics of the fibre combined with the polyurethane elastomer.

Bleaching: this treatment is carried out by using sodium hydrosulphite; a suitable optical whitening agent can also be added.

Washing

Rinsing and washing are the operations carried out most frequently during a complete textile finishing cycle. They are almost always connected to a main treatment and are aimed at removing from the fabric insoluble matters, matters already in solution or an emulsion of other impurities.
During the fabric preparation process, for example, washing is carried out after desizing, boiling and other bleaching and mercerizing processes; in dyeing, the washing stage is necessary to complete the dyeing process itself or to eliminate the dyestuff which has not been fixed; during the printing stage, washing performs a finishing action. When using vat dyes or disperse dyes, the washing process aims at removing insoluble pigment substances from the fibre surface by means of wetting or dissolving agents.
This could therefore be considered an essential treatment in the whole textile process, because of its frequent use and its strong economic impact. Manufacturers increasingly focus their efforts on reducing water consumption, which leads to subsequent energy and hot water saving as well as to a reduction in waste water. In addition to traditional washing systems with vats equipped with "vertical cylinders", the market offers horizontal washing units which reduce the liquor ratio and the energy and water consumption per kilogram of washed material.
Washing includes a chemical-physical process which removes the dirt from the substrate and a series of physical operations aimed at improving the "reaction".

The sequence of the various washing steps is the following:

a. formation of the detergent liquor (transfer of matter + energy by mixing);
b. reaching of the process temperature and wetting (transfer of the liquor to the material);
c. separation of impurities and emulsification (transfer of matter from one step to the other);
d. removal of the liquor from the fibre (transfer of macroscopic matter);
e. drying (interstage transfer of heat and matter).

These steps occur often simultaneously. The use of surfactants (detergents) during the washing stage is extremely important to speed up the wetting of the textile material, to facilitate the removal

of dirt from the substrate, thus keeping the emulsion inside the liquor and preventing the particles from laying down again on the fibre.
Important factors are water (which must be quite soft to avoid precipitation of Ca and Mg salts which could give a rough and coarse hand to the textile) and chemical products to be used (emulsifying agents, softening agents and surfactants).

Contaminants to be eliminated

The use of detergents, as well as operating conditions, depends obviously on the nature of the chemical substances to be eliminated, which need therefore to be properly classified.
A general classification is shown here below:

l) Spinning oils. We must distinguish between fabrics made with yarns spun from combed or carded fibres, which are extremely different in terms of quantity (5% and 1 % respectively) and nature of the oil added. The spinning oils most frequently used are in both cases synthetic or mineral oils. These oils are usually made self-emulsifiable by means of suitable additives (materials must always be accurately evaluated, since a wide range of products and prices is now available on the market); olein can be used for woollen fabrics (oleic acid), while for worsted fabrics a good alternative can be offered by vegetal oils;
2) Sizes. For treating wool (contrarily to cotton, where it is possible to use starch, which requires a special treatment), the chemicals now used (carboxymethylcellulose or polyvinylalcohol) can be easily eliminated and do not originate particular problems;
3) Oil stains. It is very difficult to eliminate these types of stain, due to their characteristics and to their deep penetration level into the fabric; oil stains usually require a pre-treatment with solvents sprayed directly on the stain (by means of a special "spray gun"). They can also be removed using special, expensive detergents containing solvents, or by means of dry washing;
4) Solid residues of various nature (dust, non-fixed dyestuffs, etc.), usually fixed on the fabric by means of fatty substances. To eliminate these residues, general cleansing rules must be observed and applied, and special attention must be given to the mechanical rubbing action.

It should be noted that the above mentioned statement is not at all exhaustive; in particular, it does not illustrate the treatment and the removal of severe stains (colors, metals, microbiological attacks, etc.) which cannot be treated with standard cleansing processes. The readers are therefore suggested to consult the specific literature available on this subject.

Washing machines

The scheme below shows all the categories of machines now in use; combined washing-milling machines are not included :

- Washing
  - Rope washing
    - Conventional washing
      - Traditional washing
      - Fast washing
      - Nozzle washing
    - Delicate washing
      - Conveyor belt
      - Drum
      - Combined with air
    - Washing-milling
  - Open-width washing
    - Batch-type washing
      - Traditional
      - Hammer washing
      - Conveyor
      - Hydroplus
    - Continuous washing
      - Series washing
      - Continuous line
      - Vibrocompact
      - Solvent

Washing can be performed on fabrics either in *open-width* or in *rope* form. Rope washing is more effective than open-width washing owing to a stronger mechanic action which favors the cleansing and the relaxation of the fabric structure; for delicate fabrics, an open-width washing must be preferred to avoid marks and creases. Open-width washing is also the best solution for processing huge lots.

Rope washing

Batchwise piece washing machines are substantially made up of a couple of squeezing cylinders, which make the fabric swell (the fabric is previously sewn end-to-end to take the shape of a continuous ring); these cylinders are assembled inside a vessel, whose lower part contains the detergent liquor. It is possible to wash a fabric inside this vessel by feeding it into a restricted area without laying it stretched out.
The efficiency of this operation is enhanced by the mechanical action, which facilitates both detergency and tension relaxation. This operation is highly cost-efficient, because open-width washing allows only one working position, and therefore only limited loads can be processed (max. 180 kg), while a rope washing machine can include from one to eight ropes, with an overall weight exceeding 600 kg. Furthermore rope washing machines grant reduced operating times, thanks to a more effective mechanical action.

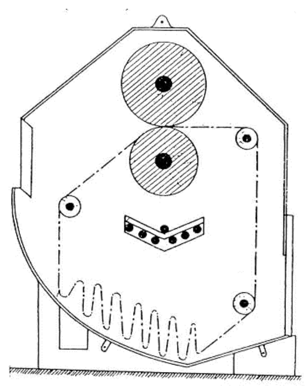


Fig. 15 Scheme of a rope washing machine

Open-width washing

An open-width washing machine is usually a system featuring a vertical path operating with driven cycle of multiple action baths, with a resulting 30-40% water and steam saving. This operating unit is manufactured in several versions (10-15-30 meters) and can be used for every kind of preparation and finishing treatment. Four different washing actions alternate inside this machine:

1) washing on rising paths;
2) washing on sloping-down paths, carried out by means of spray nozzles, which atomize on both right side and back of the fabric, performing a strong penetration action;
3) "vibraplus" effect washing, which removes from the fabric the threadlike elements (fibrils) that do not dissolve in water;
4) extraction washing by means of vessel intermediate squeezing.

The longitudinal tension of the fabric remains perfectly unchanged on the whole path; it can be adjusted between 5 and 20 kg by means of upper cylinders equipped with self-adjusting control system, which generates a sliding crease-and-fold- proof motion also on extremely delicate fabrics. Plush fibrils are removed from the vessel without any need for brushes and liquor dilution.
Another type of machine divides the washing process into single steps, which are systematically repeated. In this way the whole process can be not only constantly monitored, but also accurately calculated.

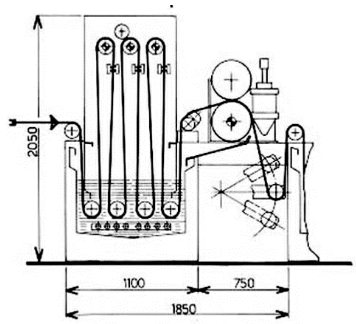


Fig. 16 Scheme of open-width washing machine

Inside every separated washing unit, an exchange takes place between the washing liquor and the chemicals mixed with impurities on the fabric in a percentage ranging between 50 and 80%. The washing liquor absorbs both impurities and chemicals. Thanks to a squeezing stage carried out by means of squeezing drums assembled at the exit of each unit, the dirty liquor does not leave the unit with the fabric. In the next unit, the liquor exchange process repeats once more, but the washing liquor contains always lower quantities of dirty particles. The regularity of the process together with the addition of fresh water are basic elements to estimate in advance the efficiency of the washing process.

These high performance washing units, equipped with double rope system and upper supporting rubber cylinders, which are recommended above all for medium and heavy fabrics, allow the maximum washing efficiency. Upper cylinders, individually driven and equipped with supporting squeezing cylinders, grant an accurate system control. In each washing chamber, the fabric is soaked twice in the liquor, which washes the fabric by passing through it and is squeezed by the cylinders. The powerful liquor exchange in the fabric is also enhanced by the synergic crosswise flow of the bath.

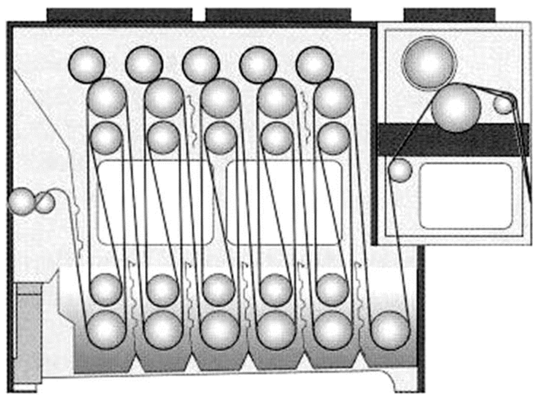


Fig. 17 Scheme of open-width washing unit

Continuous washing lines

From an output point of view, the continuous treatment of fabrics for open-width washing allows operating speeds of at least 25 m/minute: these speeds are by far higher than those obtained with batchwise open-width washing or batchwise rope washing.
The output is also strictly related to the overall dimension of the washing line (number of washing and rinsing units) and can be substantially increased. From a technical point of view, the main problems to be solved in a continuous system line are detergency and relaxation of internal tensions, especially when carried out with open-width systems. We present here below an example of a modern line, which includes:

1. a pre-washing unit, where the fabric is sprayed with a detergent solution atomized by 7 nozzles: the treatment takes place outside the bath. The solution is collected into the cavity created by the slanting path of the fabric and is forcedly driven through it (Idropress system); the alternating direction of the solution passage allows the treatment on both sides and the particular design of the driving rollers (the roller inside part is driven by a motor and the outside part by the fabric) allows a minimum tension on the fabric;

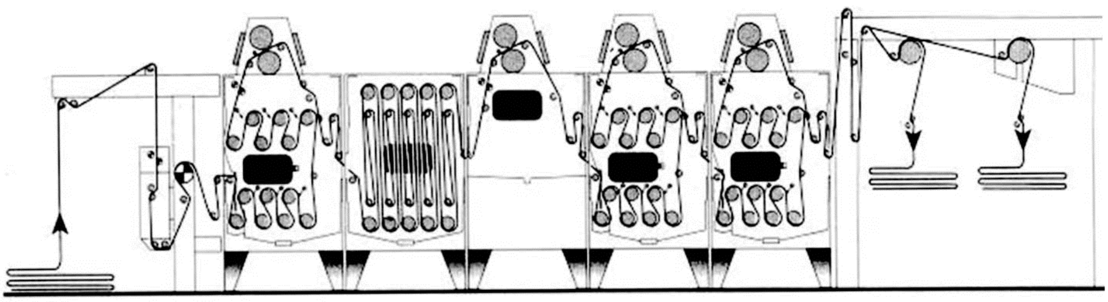


Fig. 18 Scheme of a continuous washing line

2. a soaping–washing unit (working when the fabric is not immersed in the bath), whose capacity (25 and 50 meters respectively) determines the output speed of the plant, since the time needed for the operation cannot be changed (1 min);
3. two or three rinsing units with Idropress system.

An extremely innovative machine features a basic element made up by 8 vibrating fabric guides, which push the water under pressure against both fabric sides, beating them alternatively against the fabric guides; since the flow follows the fabric motion, the effect of the driving tension is also contrasted; this plays an important role in allowing fabric relaxation in the direction of the warp (obviously, also in all other machine versions, manufacturers concentrate their efforts on keeping tension as low as possible).

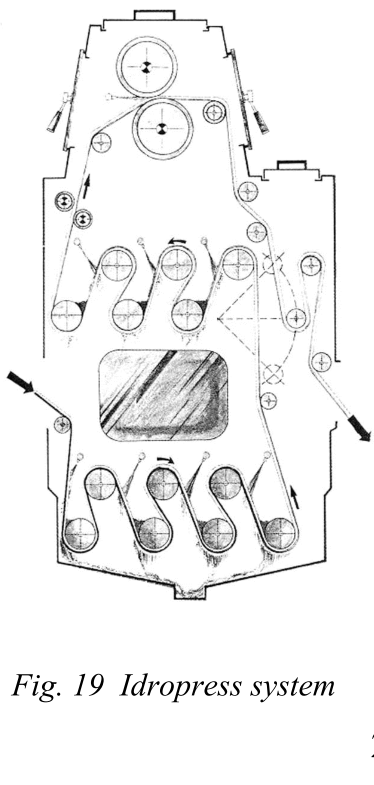


Fig. 19 Idropress system

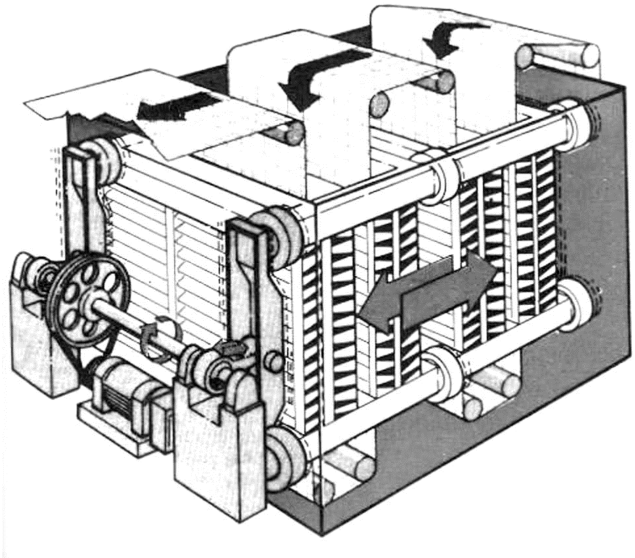


Fig. 20 Continuous washing: detail of the vibrating system

Some machines feature special water sheet devices (instead of spray nozzles) which convey a huge quantity of water, homogeneously and at high speed, on the whole width of the fabric, thus performing a really efficient wash. The system includes a pipe with a special nozzle, releasing water jets similar to blades; these water sheets perform a powerful action on the fabric and remove filaments, thickening agents, non-fixed dyestuff, etc. Many of these machines have modular structures, therefore can be adapted to specific operating requirements.

Fig. 21 Water-sheet washing system

Among all possible solutions, manufacturers offer also a counterflow washing system, in which the fabric flows from the dirtiest section of the washing bath to the cleanest section. Through a series of recycling processes, it is possible to use the washing liquor many times.
As to washing and scouring of elastic fabrics, besides traditional solvent washing lines there are at present very innovative solutions covering the treatment in water thanks with the use of new detergents which ensure adequate performance.
A basic line for this application is normally composed of an integrated system which has its core in two washing units in back flow, each one divided into two independent sections.

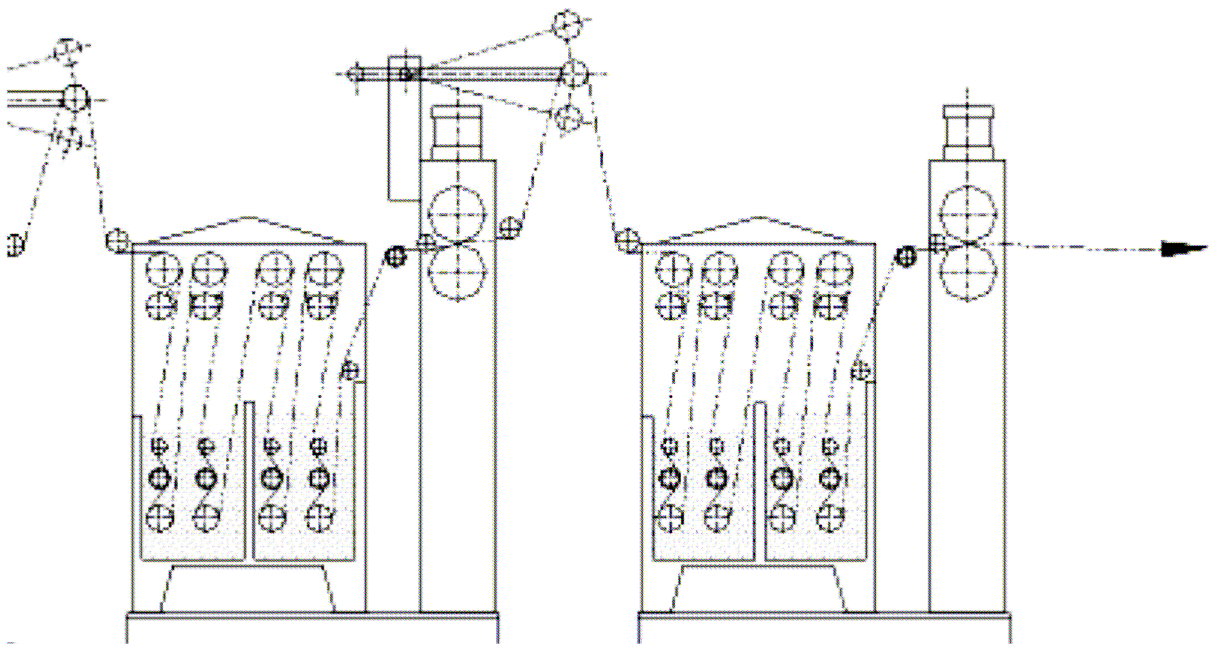


Fig. 22 Scheme of a washing line for elastic fabric

The applied technical solutions ensure following performance:

1. no selvedge rolling (each unit is provided with a series of spreading rollers).
2. possibility to shrink the fabric both in length and in width, thanks to a dragging system which develops very low tensions and permits to overfeed the fabric (individually motorized rollers ensure an advance speed independent of the speed of the dragging mangles, while pneumatically driven rocking rollers with high sensitivity and almost no friction on the rollers minimize the tensions).
3. high washing effectiveness: several nozzles per unit, operating in combination with the bath acting in countercurrent and overflowing each vessel at its entry side, ensure dirt removal and easy cleansing of the line, with consequent flexibility of use.
4. High flexibility of the line with quick adjustment of control functions to the changing characteristics of the treated fabric, thanks to new softwares and to new electronic components of last generation.

Drying

The frequency of processes which require impregnation of the textile substrate (washing, impregnation in dyeing or finishing liquor, desizing and so on), leads to the need of subsequent drying processes, with high impact on processing costs.
Depending on their nature and structure, textile fibres absorb greater or lower quantities of water; the water absorbed by the textile material is partly retained between the fibres and in the pores of the fabric and partly more deeply in the fabric by the swollen fibres. The water between the fibres or on the fabric surface can be eliminated mechanically, while the water in the swollen fibres can be eliminated with a drying process.

Notes on drying technique

The drying process aims at eliminating excess water and at maintaining the natural moisture content of the fibre. Excessive drying can negatively affect the final appearance and the handle of the textile material. It is possible to adjust automatically the drying process by means of modern electric gauges. When choosing a drying technique, the cost efficiency of the drying system must be carefully evaluated: the cost-efficiency of a drying process includes many factors, such as the quantity of steam, water and energy required to evaporate one kilogram of water, as well as the evaporation capacity of a machine, expressed in kilograms of water evaporated in one operating hour.

Adjustment of moisture content in the drying process

The drying speed is determined by the difference between the steam tension on the textile surface and the steam tension in the dryer: it rises proportionally to the decrease of moisture content in the air of the dryer chamber.
In order to keep this content on low levels, it is necessary to blow in the dryer huge quantities of dry air, which has to be heated to the same temperature of the dryer, which finally produces huge energy consumption.
When setting the desired moisture degree of the air in the dryer, it has to be considered that the best relative humidity should result from a compromise between an efficient output speed and a cost-effective energy consumption.

Adjustment of drying speed

The optimum time which a fabric spends within a dryer must correspond exactly to the time necessary to eliminate the moisture on the surface and in the interstices among the fibres; the stay time must not exceed the optimum drying time (this would cause an extra drying), since the "natural" moisture of the textile material must not be eliminated.
The feeding speed of the fabric is adjusted by means of special devices situated at the exit of the dryer, which vary the speed proportionally to the moisture of the fabric exiting from the dryer.

Heating of the dryer

The dryers are usually heated by means of steam with an average thermal efficiency of about 64%.
A better thermal efficiency is granted by dryers heated with thermal fluid (about 80%).
Highly efficient heating is obtained by means of direct gas combustion, with an efficiency of almost 95%. The operating temperature can be reached in very short times and heating can be stopped simultaneously with the machine.

Hydroextraction

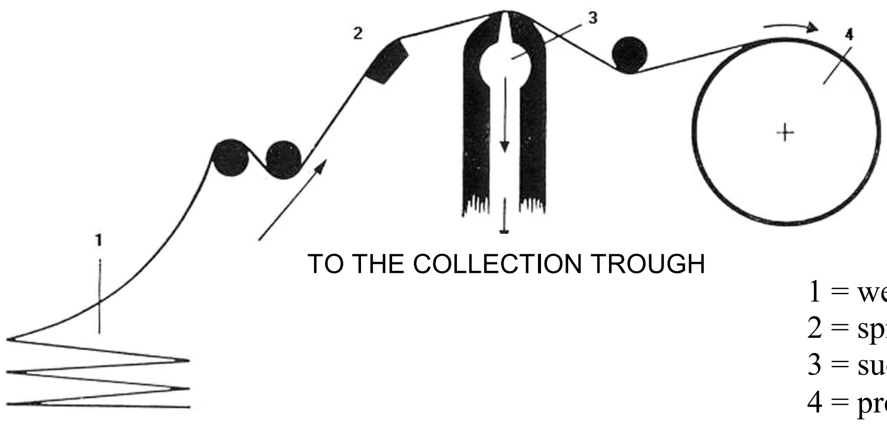
This process removes through mechanical action the water (its quantity varies according to the type of fibre) dispersed in the fibres; this process aims at reducing energy consumption and is carried out before the final fabric drying or between the various wet processing stages (washing, dyeing).
It can be carried out in the following ways:

-*by squeezing:*
the water dispersed on the surface and in the interstices of the fabric is removed by the pressure exerted by two cylinders.
- *by centrifugation:*
this process eliminates most of the quantity of water dispersed on the surface of the textile by centrifugal force. It is applied above all to resistant yarns, knitted goods and woven fabrics.
- *by steam pressure:*

steam is blown at high-speed on the whole width of the stretched fabric and passes through the fabric piece eliminating the water in excess. Extracted water and steam are condensed and reused.

- *by suction:*

this method applies vacuum technology and is used to dry very wet fabrics or delicate fabrics that do not stand up to the pressure of the cylinders of a squeezing unit, which could negatively affect the surface structure of the fabric. The stretched fabric slides in open width over the opening of a cylindric element connected to a suction system. The air drawn from the outside removes the excess water when passing through the textile material.



1 = wet folded material
2 = spreader
3 = suction slot
4 = pre-dried fabric roll

Fig. 23 Vacuum drying machine for fabrics

Drying systems

The water dispersed in a textile material by chemical-physical process is generally eliminated by the action of heat, which makes the water evaporate; during the drying process, it is very important to carefully consider the way heat is directed on the fabric.
The drying process can be carried out:
- by convection
- by contact with heated metal surfaces
- by infrared radiation
- by means of microwaves or high-frequency waves

by combustionYarns and textile materials in bulk are generally dried inside hot air compartments. For the drying of piece fabrics, manufacturers have designed different dryers, which apply different principles, briefly described here below.

Drying by convection

Heat diffusion onto the wet fabric is carried out by means of hot air circulating inside the drying chamber. There are two different types of dryers applying this operating principle: compartment dryers and tunnel dryers.

1 – Compartment dryers

Festoon dryer: it is made up of hot air compartments where the folded fabric, having a maximum width of 3 meters, is suspended on a series of rotating cylinders which lead the fabric towards the exit. The circulating air is blown slowly downward. This system is suitable for light and medium-weight fabrics that can withstand the stress of mechanical feeding.

Short lap festoon dryer: this system eliminates almost completely the tension applied by the fabric weight; it also avoids the risk of possible downward migration of dyestuff or finish.

Hot-flue dryer: the vertically folded fabric is guided through a hot air compartment. The feeding motion is determined by means of several sets of rollers, while special cylinders separate the fabric laps. The drying temperature ranges between 80 and 100°C. This drying system is suitable for printed fabrics, above all for light and medium-weight fabrics, as intermediate drying after printing, after impregnation in general, and after application of ground colours and other similar operations.

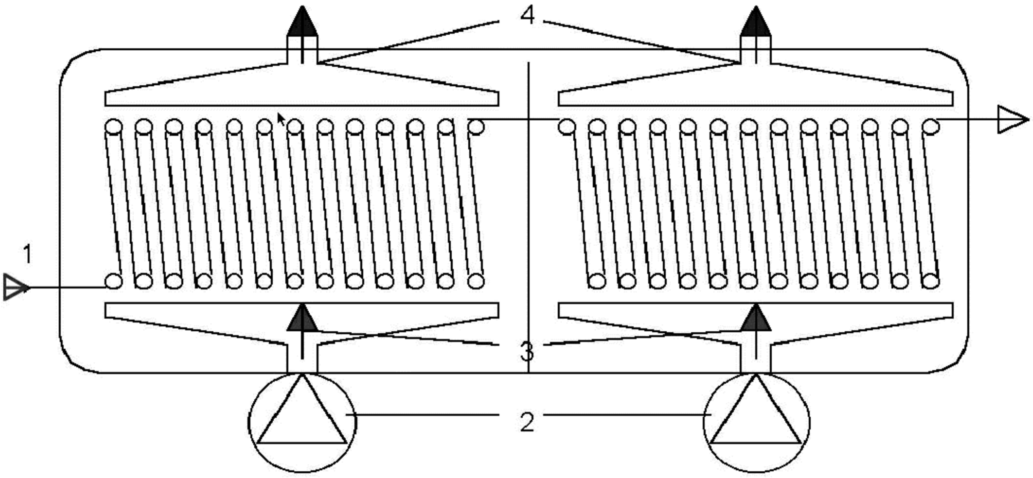


Fig. 24 Hot-flue
1 Fabric; 2 Burners-fans; 3 Hot air flow; 4 Exhausted air flow

The use of belt or perforated drum dryers is often extremely effective to cut costs and increase output rates in continuous drying processes on fabrics and yarns wound in various packages.
Thanks to the suction of hot air through the holes, the fabric adheres perfectly to the external surface of the rotating cylinders and moves forward into the dryer, where it is dried gradually.

2 – Tunnel dryers

Supporting nozzles dryers: the fabric is suspended on an air cushion generated by properly arranged blowing nozzles.

Stenter: it is made up of several modular elements named “fields”, arranged lengthwise and heated by forced hot air circulation, where the fabric runs horizontally, supported by a belt, by supporting nozzles or by air cushion.
When the hot air comes into contact with the fabric, it cools down and removes the evaporated moisture.
The air is partly drained and is replaced by an equal quantity of fresh air.
The remaining air is recycled, additioned with fresh air and passed again through the heating element.

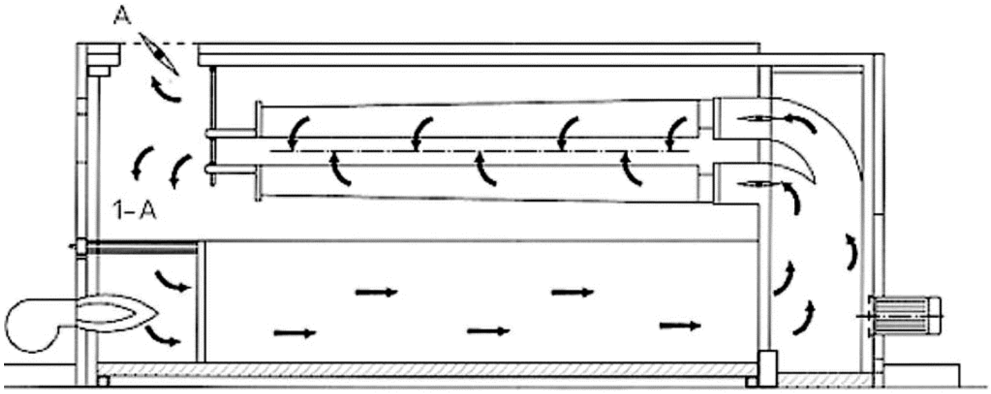


Fig. 25 Scheme of air circulation through convection in a drying stenter

This machine is extensively used in the fabric drying sector, but is also used for the heat setting and polymerisation of finishing or bonding agents in pigment printing processes; it includes a feeding area for the fabric provided with a pad-batch, where finishes and finishing products are applied or where the fabric is simply squeezed.
The use of a drum coated with porous material, which dehydrates the fabric before the drying step, proves particularly efficient.
The unit is equipped with a stretching system to keep the fabric stretched and also with a special device that controls the perpendicularity of the weft to the warp.
All the drying systems are assembled in the second section; they include a feeding system equipped with a fabric guiding system and the dryer.
The endless chains, with clips or pins for fastening the fabric, are positioned all along the front part, the drying compartment and the delivery section; they guide the fabric by the selvedge. At the delivery the fabric is released automatically from the fastening devices and wound up.

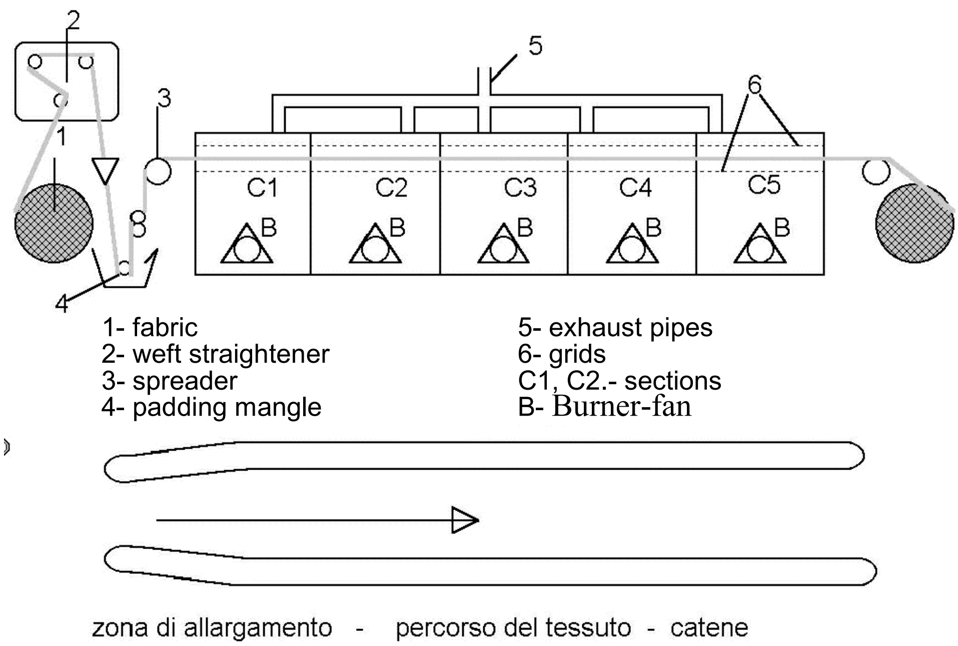


Fig. 26 Scheme of a stenter

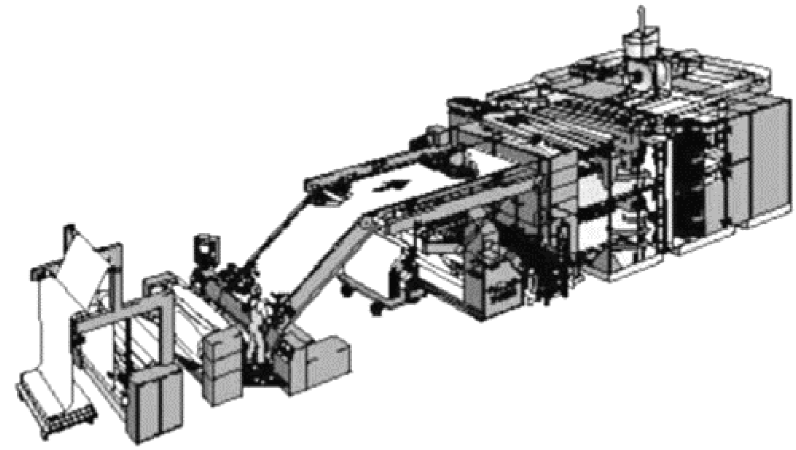


Fig. 27 Tier stenter with fabric feeding and delivery on same side

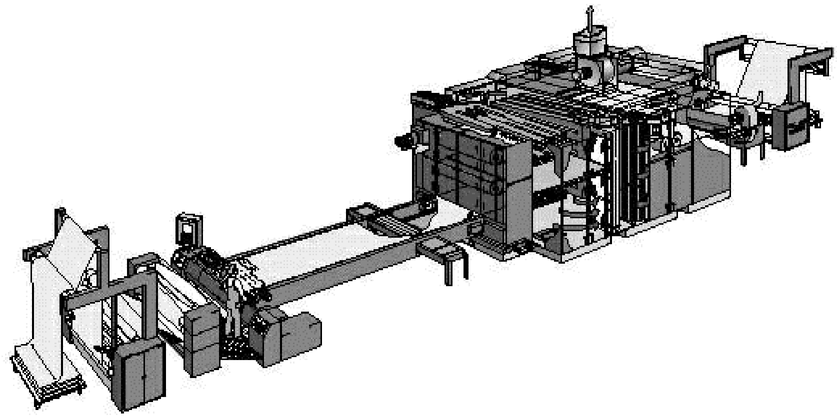


Fig. 28 Tier stenter for coating processes, incorporated into existing processing lines

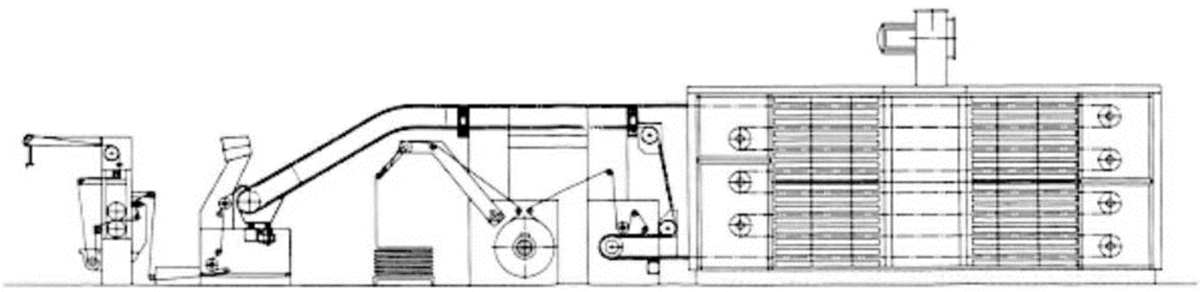
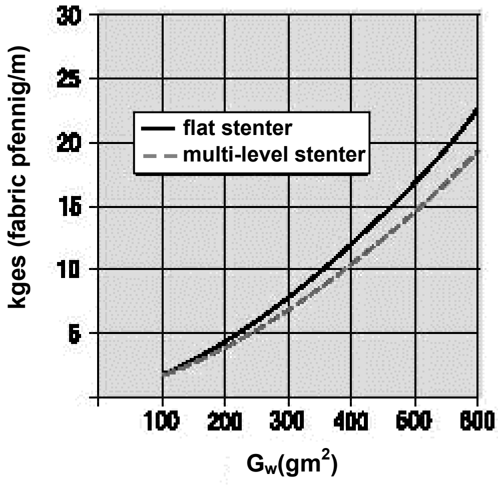


Fig. 29 Longitudinal section of a multitier stenter with internal exhaust channels

In the last generation of stenters, manufacturers have tried to improve the quality of the fabrics with more rational fabric feeding systems and innovative solutions for heat treatment and reproducibility of the various processing stages. Besides at increasing the output in continuous operating conditions, manufacturers aim at improving the machine utilization, at reducing maintenance to a minimum and at cutting energy consumption.

Multitier stenter

Thanks to an excellent capacity/overall size ratio, the multitier stenter is also particularly cost effective for treatments requiring a certain stand-by time, such as for example heat setting of man-made fibres, chemical treatment setting and carbonizing. The diagram compares the drying costs expressed in kges of a flat stenter with those of a multitier stenter depending on fabric weight gw.



Advantages of the multitier stenter:

- Compact structure: thanks to the multi-level design, the overall space required for the installation of the stenter is much less than for a standard flat stenter with same capacity.
- High-performance in the drying process: for heavy-weight textiles, the efficiency of the machine does not depend on the evaporation on the surface, but on the time required for the drying process. Powerful ventilation, generally applied to flat stenters, could cause an excessive drying of the textile surface and damage the material, while fibres inside the fabric could remain wet. The internal moisture migrates very slowly to the surface.
- Delicate drying: in a multitier stenter, the drying process does not affect the material negatively and eliminates the moisture in the best possible way. In fact, we know that a delicate treatment, e.g in a drying or heat setting process, can be ensured only with a slow ventilation of the material. Furthermore a longer treatment time, even at lower temperatures, gives a better appearance to the finished material, compared to tougher treatment conditions. The result is a bulky fabric with softer hand, which gives the sensation of heavier weight.
- Lower operating costs: this is due to the reduced number of operators, to the reduced space requirement, to the lower yield reduction when treating heavy-weight textiles and to the reduced consumption of energy at same output rate in respect to a flat stenter.

Limits of multitier stenters:

- only some multitier stenter models can be equipped with pin chains.
- in the path between one level and the next one, the fabric must be sustained to avoid the formation of wrinkles and therefore deformation. Telescopic drums are used to convey the piece of cloth by moving forward the whole fabric width, thus sustaining it from one selvedge to the other; unfortunately on delicate textiles, such as raised velvets and very lustrous viscose fabrics, this system causes evident and unpleasant stripes and marks on the surface.

Fig. 30 Flat stenter

Contact drying

Drum dryer: with this system the fabric moves forward arranged on several heated drums. The drying temperature ranges between 120 and130° C and the cylinders are heated by means of steam at a pressure of 1-3 atm. This very efficient and low-cost drying system is particularly suitable for flat fabrics with slightly evidenced structure, which cannot be negatively affected by tension during feeding. Used for intermediate drying and for light finishes, this system is not suitable for durable finishes with thermosetting resins.

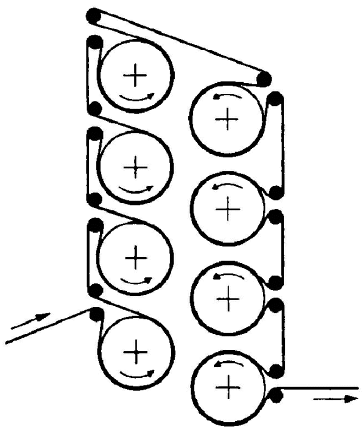


Fig. 31 Scheme of a drum dryer

Infrared radiation drying

Infrared radiation (near and medium infrared field) can be absorbed by the fabric and transformed into heat by energy "degradation".
In fact their absorption is proportional to the "excited" vibration levels of the bonds of the atomic groups, from which the passage to the basic level takes place by means of energy release.
Therefore only radiations with a wavelength corresponding to the absorption levels of the textile material are absorbed by the textile material and then transformed into heat.
The capacity of some radiations to penetrate deeply corresponds to the possibility to develop heat inside the textile material.

This can be demonstrated for example by cellulosic fibres, whose absorption spectrum in the near infrared field is such as to present following characteristics:

a) radiation with wavelength λ= 2.5 µm, only partially absorbed: it releases a small quantity of heat and passes through a very thick textile.
b) radiation with wavelength λ= 3 µm, highly absorbed by the fabric: it does not penetrate the surface, to which it releases all its energy in form of heat.
c) radiation with wavelength λ= 3,4 µm, corresponding to a medium absorption: it partially penetrates the material and creates a heat source inside it.

Water absorbs infrared radiation too (its maximum absorption is equal to 3 µm).
If we think that this absorption wavelength applies to almost all textile materials (cellulosic, polyamide and protein fibres) as well as to water, the same area can be considered the most important section of the infrared field for the drying process.
In fact these radiation levels produce, in almost all textile materials, an excellent absorption coefficient on the surface and therefore a quick heating potential, which leads to an excellent thermal efficiency.
This section represents only a small part (from 3 to 7%) of the infrared radiations emitted by a standard source.
The 3 µm radiations are also absorbed by steam, while the radiations with lower λ pass through the steam with insignificant absorption levels.
The infrared radiation sources generally used are characterised by a different emission spectrum and can be divided into three main categories:

a) short infrared radiation lamps;
b) incandescent emitters (for medium infrared radiation)
c) no-light infrared emitters (for long radiation).

The presence of sizes, dyes and finishing products on the fabric does not modify the absorption spectra and therefore has slight impact in most cases.

Microwave drying

Application of microwaves and high frequencies in fabric drying

The heat transfer from the surface to the inner part of the fabric takes place with a certain difficulty due to the poor thermal conductivity of the fabric, with consequent difficulty in obtaining a temperature uniformity in the whole heated mass in a relatively short time.
By means of radio frequency waves, heat develops inside the material in a quantity proportional to the water dispersed in it.
In fact water molecules, when subjected to an electric field, are polarised and therefore oriented along the lines of this field: if it is an alternated electric field, to each field displacement corresponds an inversion of the polarisation direction.
Consequently in an alternated electric field water molecules are forced to oscillate with the same frequency of the field, thus dissipating energy by effect of molecular friction.

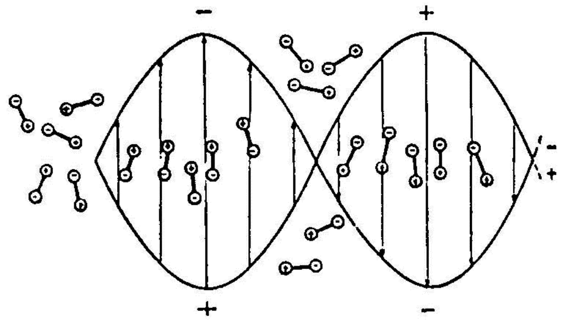


Fig. 32 Action of the electromagnetic field $P = K . E^2 . f . s$

Dipolar molecule *Electromagnetic field vector*

The work produced by this oscillation heats the material (with no need to heat by contact or convection) and the heat quantity developed depends on the frequency and on the intensity of the electric field as well as on the oscillation power of polar molecules. This capacity of non-conductive molecules is expressed by a dielectric quantity called loss or dissipation factor:

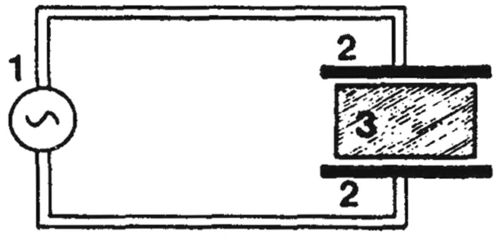
$$P = K . E^2 . f . \sigma$$

where
K = numerical constant
E = intensity of the electromagnetic field
f = frequency of the electromagnetic field
σ= material loss factor
Only polar or polarisable materials with specific translational and/or rotational freedom can be heated, while textile polymers with stiffly linked long chains do not have a suitable structure to vibrate and therefore to absorb energy. For this reason, the water dispersed in a textile material, thanks to its polarity and to its mobility, has a "loss factor" about 100 times higher than the dry fibres.
Therefore a wet material can absorb a quantity of energy proportional to the water dispersed in it: the more the moisture goes down, the more the dissipated energy decreases.
Furthermore, if the moisture is dispersed irregularly in the fabric, a greater quantity of heat will develop in the areas with higher water content, with consequent higher evaporation. This leads to a fast and homogeneous thermal action which stops the drying, once the desired moisture content has been reached, by simply controlling the dissipated power. The apparatus includes a conveyor belt running in an area where a strong magnetic field inverts rapidly its polarity, thus offering a quicker system compared to standard warm-air dryers, with a smoother final drying and accurate residual moisture values. The design of special electrodes allows the transfer of radio frequency energy simultaneously with the delivery of warm air. Considering that the penetration depth of electromagnetic waves is inversely proportional to their frequency, in order to avoid signals interfering in telecommunications the following international frequency bands have been assigned to these drying systems:

Radio frequency:	13.56	and	27.12 MHz
Microwaves:	915	and	2,450 MHz

Usually high frequency is applied to very densely wound packages (hanks, cones, bales) or to produce fast binding of latex layers, whereas microwaves are used for high-speed thermal treatment of yarns and fabrics.

A radio-frequency dryer includes following elements:
a) generator
b) electrodes
c) drying chamber



High frequency drying

1 Source of electric current
2 Condenser plate
3 Material

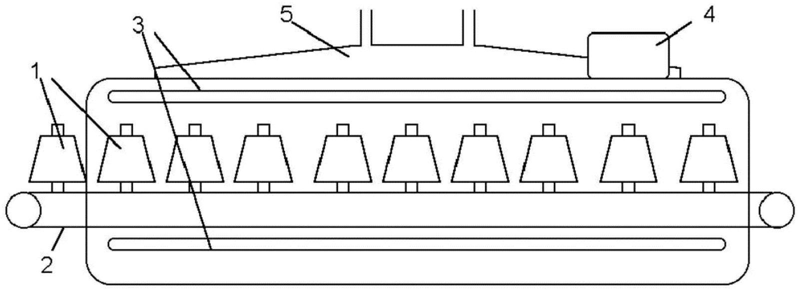


Fig. 33 Illustration and operating schemes of a radio-frequency dryer
1 – material 2 – conveyor belt 3 - electrodes 4 - generator 5 – steam exhaust

Combustion drying (Remaflan process)

Fabrics are dried by exploiting the combustion heat of an organic solvent spread over the fabric.
The application of the finishing products is carried out by padding their solution in a hydro-alcoholic mixture, composed of about 36% in volume of methyl alcohol.
The fabric enters vertically into the dryer on the vertical axis of the pad-batch, where a short path through infrared heaters gives rise to the evaporation of the methyl alcohol and to the ignition of the vapours (the ignition temperature ranges between 31 and 37°C, according to alcohol concentration; the ignition temperature of anhydrous methylalcohol is 11°C).
Since the size of the drying tunnel is very small, the temperature in the combustion area reaches 600-750°C; if we consider that a liquid evaporates by heat absorption, the treated fabric, when releasing its moisture, maintains a temperature ranging between 45 and 70°C, which allows delicate and fast drying.

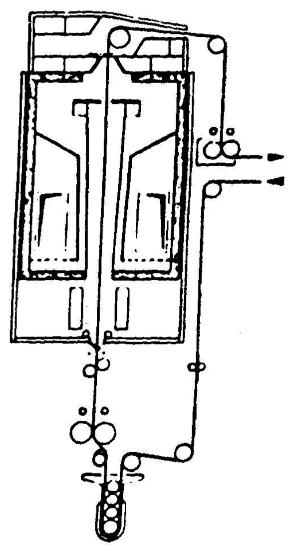


Fig. 34 Scheme of combustion drying

The fabric feeding speed, depending on its characteristics, is adjusted by means of automatic devices according to the residual moisture desired (in medium-weight fabrics, the speed is about 40 m/min). Since the evaporation of methylalcohol requires less energy than the evaporation of water and since only CO_2 and water originate from its combustion, Remaflan process proves to be not only a cost-efficient, but also a pollution preventing drying method.

THE COLOUR

One of the major problems which come about in the finishing field is the necessity to reproduce customers' shades in the shortest possible time, with as much accuracy as possible, at lowest possible costs and in compliance with the technical specifications. Meeting these exigences requires from the operators technical skill and experience along with a proper company know-how.
We should however not forget the role played by the subjectivity of view and by the consequent disparity in judging both colour reproduction and the acceptance of shade differences, when the assessments are made by different operators (which may differ in terms of age, of physiological, emotional and cultural factors and also in terms of functions); this disparity in judgement implies often discussions, resentment, delivery delays and sometimes rejection and even return of goods delivery, with considerable costs and/or loss of customers.
As it is not possible to examine here thoroughly this subject, we shall just mention the principles which rule colour vision and the tools which technology puts today at the disposal of the operators of this sector to facilitate their task.

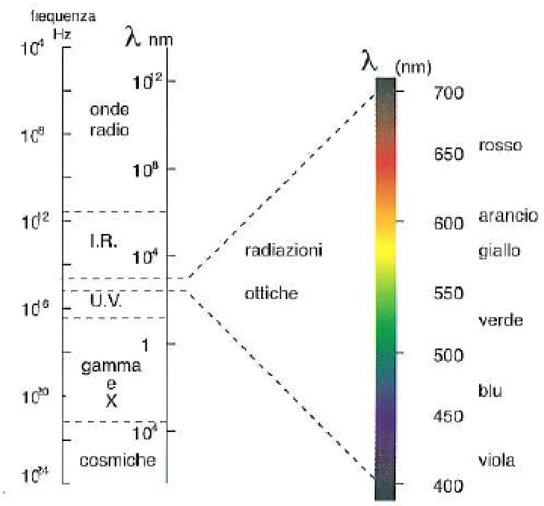
Light and colour

Colour is a subjective interpretation of a stimulus perceived by the human eye.
In order to be able to see a coloured object, it is necessary to have the following:

a) a source of electromagnetic radiations in the visible field (from 380 to 760 nm), which source is commonly named ***illuminant***
b) an object capable to interfere with the radiations which are hitting it (***absorption, reflection, diffusion***)
c) a detector: the combination eye-brain which ***detects and analyses*** the radiations, both direct or reflected, which reach it, to ***interpretate*** them as an object of a defined ***colour***, or the combination of a colorimeter or of a spectrocolorimeter with a computer provided with suitable software.

a) Light and illuminants

What we perceive as "light" is nothing but a beam of electromagnetic radiations with an λ between 380 and 760 nm. The illuminants are sources of such radiations.



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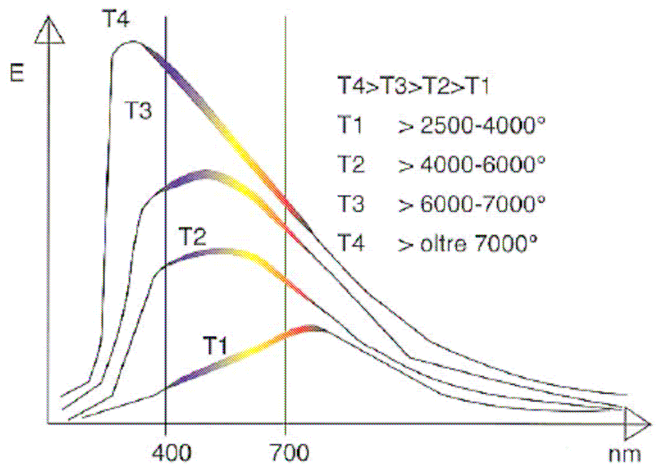


Fig. 35 Electromagnetic radiations and spectrum of the visible

Fig. 36 Emission curves of the blackbody

The different wave lengths are perceived and interpretated as colours (see spectrum of the visible indicated in Fig. 35 and in the annexed table), whereas a radiation beam containing all the λ in "equal quantity" is perceived as a white light (additive synthesis).
The single illuminants differ from each other in the spectral composition of their emissions and can be classified on basis of their Colour Temperature (temperature in °K which the blackbody shall reach to get an emission spectrum superimposable to the spectrum of the illuminant).
In other words, the light emitted by the blackbody will constitute a continuous spectrum, whose composition will vary with the temperature (according to Planck's law) and result more balanced (white light) for colour temperatures between 5500 and 6500°K; at lower temperatures, the yellow-red component will prevail, whereas at higher temperatures the blue-violet component will prevail (Fig. 36 and annexed table).

C.I.E. (Commission Internationale de l'Eclairage) defined (and/or standardized) the spectral composition of the illuminants usable for colour evaluation; we give hereunder some examples (Fig. 37):
Type A illuminant: Planckwise illuminant (spectral emission which follows Planck's law), obtained through tungsten filament brought to incandescence in extremely rarefied atmosphere; its colour temperature is 2856°K. This illuminant is the same as used in common incandescence lamps employed for domestic lighting, which emit a (standardized) yellow-orange light.
Type B iIlluminant: Non-Planckwise illuminant (not following Planck's law), obtained by properly filtering a type A illuminant. Its colour temperature is 4874°C and intends to imitate midday light facing north in a fair day.
Type C illuminant: Non-Planckwise illuminant; it is obtained by properly filtering a type A illuminant or other illuminant. Its colour temperature is 6774°K and intends to imitate midday light coming from north with a cloudy sky and has white-blue colour (defined colour).
Type D65 illuminant: Standard illuminant recommended by C.I.E., with a colour temperature of 6504°K, obtainable by suitably filtering Xenon lamps, tungsten filament lamps or fluorescent lamps. In each case it corresponds to an average diurnal light measured in different moments of the day, quite similar to type C illuminant but richer in (**standardized)** near-UV radiations.
Type F illuminant: this is a Philips TL84 lamp used for the illumination of shop windows, among which those of Marks & Spencer warehouses, with a colour temperature of 3900°K.
Type E or W illuminant: theoretical equienergetic illuminant (never used).

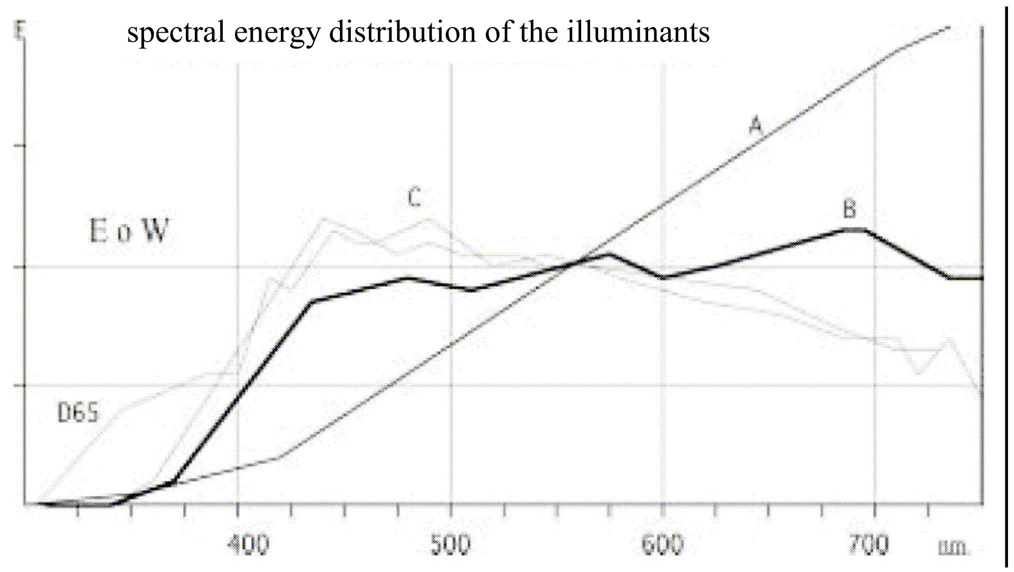


Fig. 37

b) Object, reflection, absorption, diffusion

When a beam of luminous radiations with certain spectral composition hits an object, following phenomena can occur:

1. Reflection
2. Diffusion
3. Refraction
4. Absorption

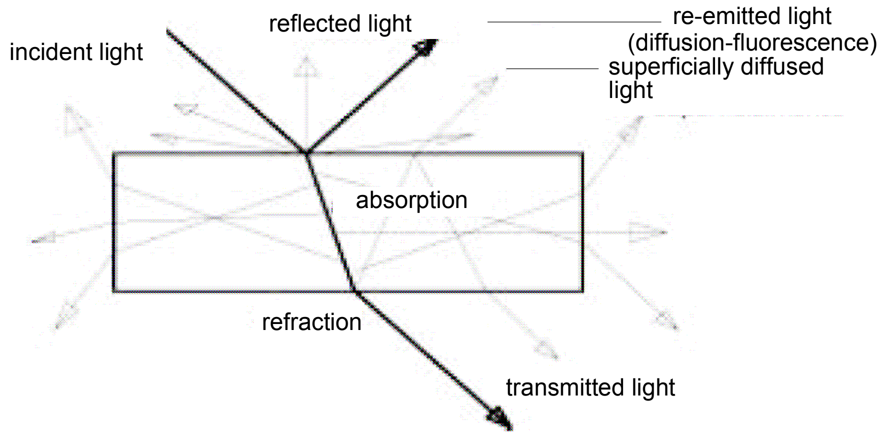


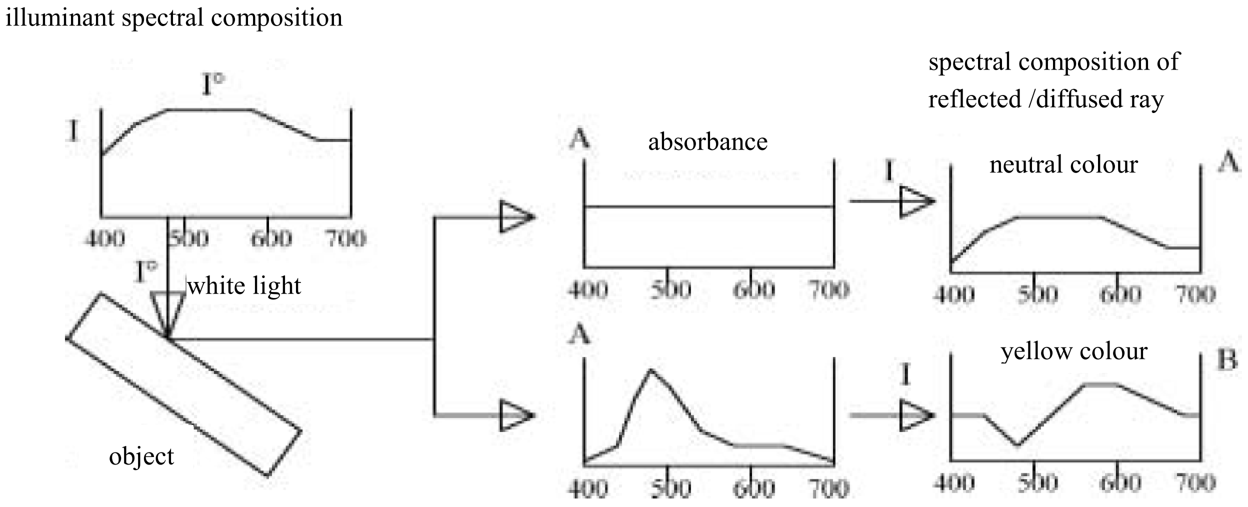
Fig. 38 Interaction light/matter

Reflection
We have a specular reflection if the reflection angles with respect to the normal in the incidence point of the radiations on the obiect are equal to the incidence angles.

2. Diffusion
We have a diffused reflection if the reflected radiations are partly oriented in all directions owing to a surface composed of various differently oriented micro-planes or/and, in case of translucent bodies (partially transparent), also owing to a series of internal refractions, reflections and diffusions which cause the re-merging of radiations with various directions, more or less modified in their spectral composition.

3. Refraction
If the material composing the object is transparent (or partially transparent), the radiations will pass through it and re-emerge at the opposite side, originating at their entrance and exit the phenomenon of refraction, i.e. a deflection of the beam in respect to the axis, at its entrance and at its exit from the body.

4. Adsorption
If we send a radiation beam containing all λ of the visible range onto a semi-transparent or semi-dull body, some molecules contained in it could enter into conflict with the radiations; in this case the intensity of the outgoing beam (reflected and/or diffuse beam) is lower than the one of the entering beam; practically an interference (adsorption) by the molecules of the object has occurred.
If the adsorption is selective, i.e. has an intensity varying at the different λ values, the outgoing beam, besides having lower intensity, has a spectral composition different from the entering beam (subtractive synthesis, see enclosed table at the end of this Notebook), with consequent perception of the complementary colour.



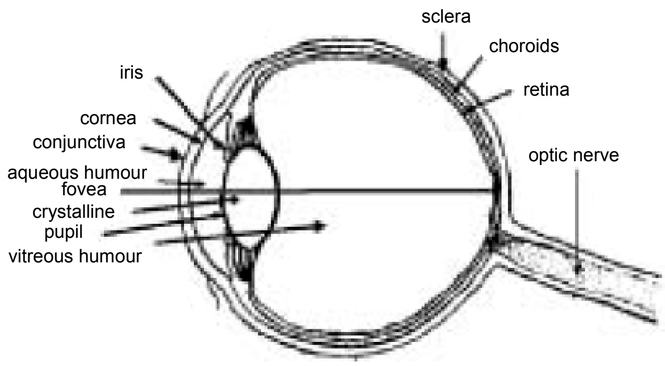
The ensemble of all above mentioned phenomena is responsible for the appearance of our object, whose surface can be smooth, wrinkled, satinized, bright and whose colour can have different tonality, saturation and brilliance.

c) Detectors

1. Eye and colour perception

The human eye as presented here below acts as a videocamera by focusing the images in the fovea, the zone in which the cones and the rods are situated.

The cones are nerve endings which serve as photoreceptors, with a sensibility much lower than the rods but in a position to distinguish the different λ, with the ensueing possibility to "interpret" the various spectral colours and all reproducible colours through additive synthesis (see enclosed table).



It is by now ascertained that there are three types of photoreception cones which differ because of the different sensibility curves at the various wave lengths, with peak values at 440 nm, 535 nm and 570 nm (Fig. 39 and enclosed table).

The rods are more sensible than the cones to the electromagnetic radiations, but have not the capacity to distinguish the various λ and are used for night vision.

λ MAX. SENSIBI LITY OF THE THREE CONE TYPES

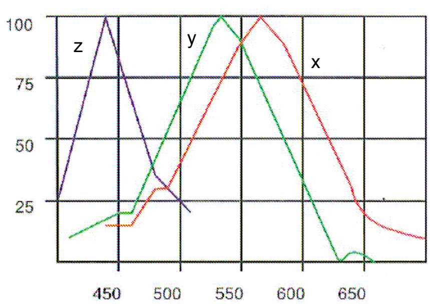


Fig. 39 Sensibility curves of the photoreception cones

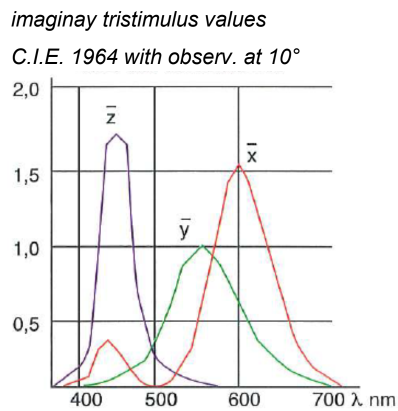


Fig. 40 Blue green red stimulus
z blue y green x red

Research works on the *theory of colour vision* permitted to explain the complex mechanism with which the visual apparatus intercepts the radiations throuth the photoreceptors, transforms them into signals and interprets them through the cortex of our brain, to generate the colour sensation by means of an additive synthesis. Let us see the most importat theories:

Young-Helmholtz theory (or theory of the three components)

Helmholtz resumed and perfected the studies of Thomas Young; this theory is based on the existence of three different receptor types, which are excited respectively by red, green and blue radiations.

According to this theory (Fig. 39), the radiations of the visible spectrum stimulate in different ways the three cone types depending on the sensibility curve of these last and on their spectral composition. Each type of cone sends to the cortex a signal of its own, which is codified in form of electric potential; in the cortex these signals are decodified, summed up and interpreted as colours, also on the basis of the memory of the person in question.

Muller theory (or multiphase theory)

This theory is more recent (1930) and is based on a multiphase mechanism. At first, as supposed for the three components theory, the three different cone types generate three different signals. Subsequently, these signals are codified in their passage through particular cells into three new stimulus, one of which proves to be achromatic (brightness), while the other two stimulus are chromatic in opposition (yellow-blue, green-red, white-black). In the third phase, the cortex decodifies such stimulus and interprets them as colours also on basis of the visual experiences gathered by each single observer.

C.I.E. defined the average observer (**trichromate**) codifying it with the **colormatching 1931 (now C.I.E. 1964) functions** (see Fig. 40 and enclosed Table).

However we must not forget that there are also individuals with heavy troubles in colour vision, as **colour-blinds:** this colour vision defect is of hereditary recessive type. There are also colour-blind individuals named dichromates, who have only two types of cones.

The majority of the persons with defects in the vision of red colour is anyway composed of **anomalous trichromates** who possess one cone type (red or green) with maximum sensibility towards λ which is different from normal trichromates.

Even if defined as "normal", the human eye can always present some small differences from one individual to the other as far as transparency of the various parts are concerned, as cornea, aqueous humour, vitreous humour, crystalline and macula lutea, with consequent light alterations of the spectral composition of the radiations, which reach in filtered status the cones. Moreover, even if in the same individual, time too brings about some alterations; usually the maximum capacity in colour selection is achieved at about 25 years of age; after this date a slow but steady decrease of this capacity, owing to transparency reduction and particularly to the yellowing of the crystalline, takes place.

Consequently it is evident that also an individual who has a normal colour perception will not be able to carry out an objective and reproducible assessment. We are not endowed with colour memory so that, even after short time, we are not in a position to establish if an already seen colour is qualitywise and quantitywise the same as a similar colour observed some minutes before.

2. Spectrocolorimeter and colorimeter

The instruments used to assess the colours consist generally of a **light source**, a **sample holder** and a **sensor** or **signal detector.**

The procedure is the following: the coloured sample, hit by a radiation beam of known composition emitted by the illuminant, varies radiation composition owing to absorption-diffusion; the reflected/diffused beam thus modified is analysed by the detector. The detector (photocell or

photovoltaic tube, CCD sensor) is able to record the presence of electromagnetic radiations and to transform them into electric signals with an intensity proportional to the energy of the radiation flow which hit it; the sensibility and precision can be very high, but the detector is not able to give an information on the spectral distribution of such radiations.
According to the identification system of the spectral composition, we can differentiate the apparatus as follows:

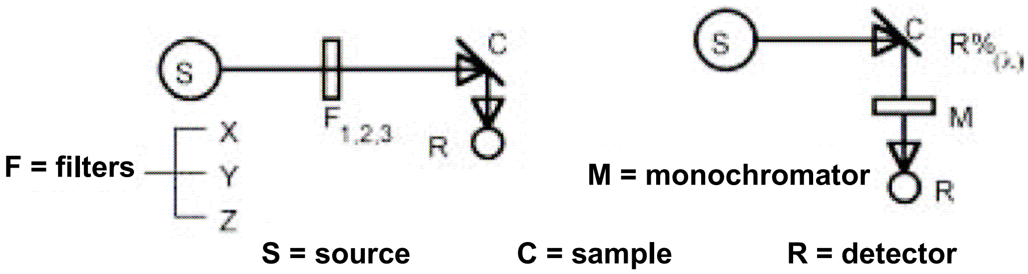


Fig. 41 Scheme of a colorimeter *Fig. 42 Scheme of a spectrocolorimeter*

Colorimeter: this is equipped with three filters which permit to trace back directly to the X, Y and Z values of a colour read through a suitable software; the values can then be used in all applications of instrumental recipe prediction and quality control. These instruments are precise, not much expensive and very handy, but do not permit to get the reflectance spectrum of the colour, with resultant limits in their use (Fig. 41).

Spectrocolorimeter: this is equipped with a monochromator in order to have the possibility to record the reflectance curve; it is more precise than the colorimeter and permits a wider application field, but is also more expensive and less handy.
It works as follows:
Various series of flash are sent onto the coloured samples; a monochromator placed between the radiations reflected/diffused by the sample and by the detector lets the radiations with prefixed λ (e.g. from 400 to 700 nm every 20, 10 or 5 nm) pass in rapid sequence; the instrument will read the signals related to the corresponding λ values.

λ	400	420	440	460	480	500	520	540	560	580	600	620	640	680	700
R%	10	22	20	18	16	14	25	40	70	82	91	80	73	65	58

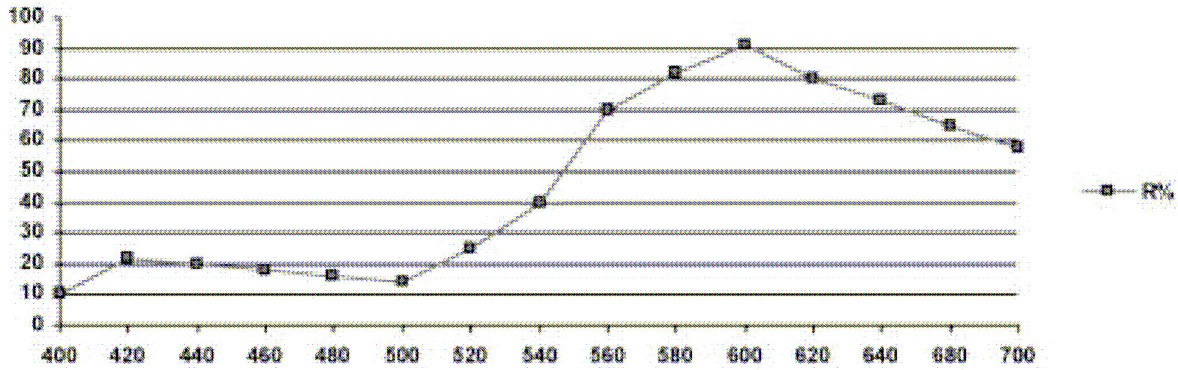


Fig. 43 Reflectance diagram

The signals sent to the data processor and interpreted through proper software are recorded as reflectance values (R%) with respect to the white standard at the various selected λ values, after averaging out the readings (if the readings differ over the prefixed limits, they must be repeated).

The processor can display the results in form of a reflectance curve (Fig. 43) and, in case of necessity, modify them mathematically according to the type of illuminant which will be used (provided that the emission curve of such illuminant is covered by the software in use) or transform the data into X, Y and Z values (Fig. 42).
As to the illuminant, although the one used is sufficiently stable, the emission spectrum can slightly vary in the course of time (depending if the lamp has been just lit or has been operating various hours, if it is new or has run 1000 or 2000 hours), thus providing unreadable reading data. For this reason, each time the instrument is started, it is indispensable to calibrate it against a sample which is considered to be of ideal whiteness (BaO-white earthenware tile or other material, supplied together with the instrument); the reading of the white colour is considered as reflectance of 100% at each λ. With some softwares, a subsequent reading of a black sample is required.
The coloured body reflects partially the radiations, but diffuses them partly in all directions. For this reason, all spectrocolorimeters are equipped with a device able to collect and transmit to the detector both reflected and diffused radiations, or only the diffused radiations or only the reflected radiations, with different geometry according to the exigences; it is therefore possible:

a. to illuminate the sample with 0° angle and collect the diffused radiations (0°/d).
b. to illuminate the sample with diffused light and collect the radiations with angles 0° (d/0°), 2° (d/2°), 10°(this last is the most common method for the evaluation of the fabrics).
c. To illuminate the sample under a certain angle and collect the radiations under same angle (0°/0° as used for reflected radiations).

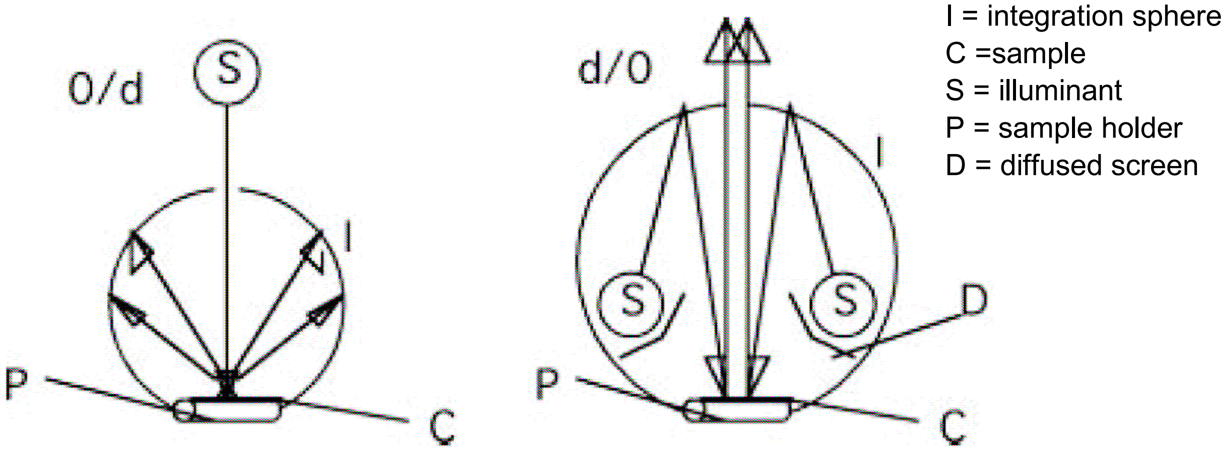


Fig. 44 Examples of geometry

Fig. 45 Spectrocolorimeters and portable colorimeters

C.I.E. 1931 System

The study of colorimetry inteprets the colours by means of a geometric-mathematical space based on the trichromatic components of three reference stimulus (or vectors) X, Y and Z assessed through "measurement" systems based on "objective" receptors, therefore independent from environmental, physiological and/or psychological factors (based anyhow on the principle of the visual trivariance of the human eye).
C.I.E. (Commission Internationale de l'Eclairage) adopted a mathematical space of the colour named C.I.E. 1931 (which was followed by C.I.E. 1964) by moving from following premises:

1. **Standardization of the illuminants** (see definitions and Fig. 37)

2. **Individuation of the imaginary reference stimulus $\mathbf{X}_{(2)}$, $\mathbf{Y}_{(2)}$ and $\mathbf{Z}_{(2)}$** (in C.I.E. 1964: $\mathbf{X}_{(10)}$, $\mathbf{Y}_{(10)}$ **and** $\mathbf{Z}_{(10)}$) and of colour-matching functions (Fig. 40 and enclosed table)

3. **Y stimulus and brightness**
The Y stimulus has been used by selecting for λ a value corresponding to the value of maximum sensibility to light of the standard observer, and has been assumed as base index for the brightness.

4. **Right-angled triangle geometry**
The three stimulus X, Y and Z are used as 90° oriented vectors, thus generating a colour space with a right-angled triangle-shaped unitary space; this space is suitable for mathematical calculations and therefore is the basis for instrumental recipe calculation (see Fig. 46 and enclosed table).

Colour specification
In this space, as soon as the three values X, Y and Z defined through spectrocolorimetric reading of a colour are fixed, a point in biunique relationship with that colour is localized.

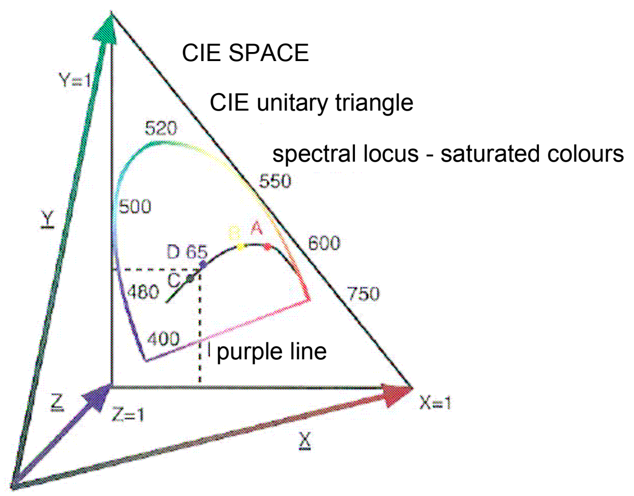


Fig. 46 C.I.E. space

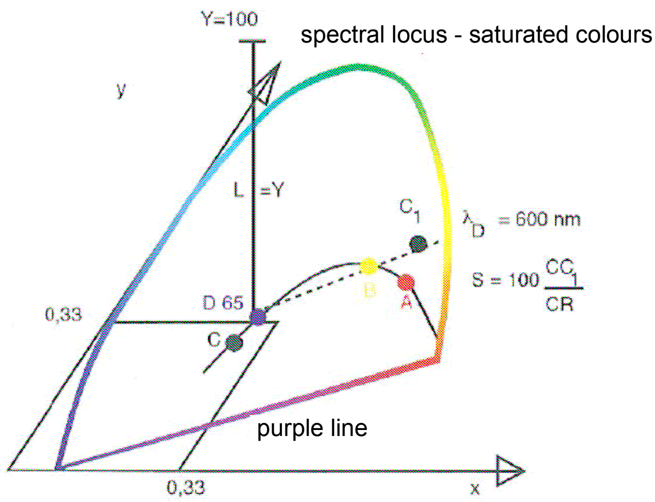


Fig. 47 Chromaticity diagram x, y, Y

If we start from the position of a colour in the C.I.E. space defined with X, Y and Z values, we can obtain an achromaticity diagram, on whose unitary plan the brightness Y (related to 100 for the used illuminant) is positioned perpendicularly to the chromatic point of the illuminant, while the colour point is located through the trichromatic coordinates x, y and the brightness Y is defined as above (see Fig. 47 and enclosed table), where:
x = X/X+Y+Z

$y = Y/X+Y+Z$
This way we shall have always :
$x+y+z = 1$
It is also possible to specify a colour through magnitudes which make its interpretation easier :
After establishing within the chromaticity diagram the position of colour C_1, the achromatic point is connected to C_1 and the segment is extended so far as to cross the curve of the spectral locus, while identifying the **dominant wave length or λD** (identifying the tone). If the extension falls on purpura line, the segment will stretch out in the opposite direction, locating on the curve of the spectral locus the value of **λD.**
The **saturation level** will be given by the ratio between segments CC_1 and CS related to 100 (a 100% saturated colour is monochromatic or spectral, that is formed by a radiation containing one l only).
The **brightness level** will always be the value of the Y stimulus existing in the colour, related to 100 for the used illuminant (Fig. 47).

Colour difference, metamerism

What above permits to identify a colour in an objective and univocal manner within a mathematical space.
Let us consider two similar colours within the mathematical space: if we link the distance between the two points (colours) to the colour difference and express it with an objective numeric value (DΔ), we have thus defined through a number and therefore objectively the difference between two colours. In this way we can calculate the differences between a sample and one of its imitations.
In order to solve several problems connected with subjective evaluation, scholars tried to define through experimental tests the chromatic tolerance, viz. the maximum acceptable (not perceivable) DΔ value within the reproductions of a colour. In order that the above said is practically usable, it is necessary that the measured tolerance limit corresponds to the threshold of visual perception of the difference between two colours by the average observer. The calculation of DΔ within the C.I.E. space (both 1931 and 1964) does not permit such results, because this space is not perceptibly uniform (it is uniform in the Munsell atlas - see enclosed Table -, which however is not a mathematical space), therefore it does not suit the intended purpose. Consequently scholars worked out the UCS spaces (approximately uniform spaces, e.g. CIEL*a*b* 1976 and others, which are related to the Muller theory)(Fig. 48 and enclosed table) which better suit the colour perception by the average observer; within these spaces the colour difference (DΔ*) is evaluated through special formulas (which already comply, or are modified to comply with the minima perceptible thresholds of a standard observer).

CIEL*a*b*1976

$$a^* = 500\,[(X/X°)^{1/3} - (Y/Y°)^{1/3}]$$
$$b^* = 200\,(Y/Y°)^{1/3} - (Z/Z°)^{1/3}]$$
$$L^* = 116\,(Y/Y°)^{1/3} - 16$$

CIEL*h*c*1976

$$L^* = 116\,(Y/Y°)^{1/3} - 16$$
$$C^*ab = (a^{*2} + b^{*2})$$
$$h = \arctan(b^*/a^*)$$

X/X°, Y/Y° and Z/Z° > 0,01 :

$$\Delta E_{CIE\ L^*a^*b^*} = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{1/2}$$
$$\Delta E_{CIE\ L^*C^*h^*} = [(\Delta C^*)^2 + (\Delta h^*)^2 + (\Delta L^*)^2]^{1/2}$$

X°, Y° and Z° are the tristimulus values of an ideal white pertaining to the used illuminant, with Y° = 100 for any illuminant whatsoever.

The value of the colour difference DΔ generally used as tolerance limit is l, but this value is subjected to vary depending on the applications, on the destination of the products and on the agreements between producer and customer.

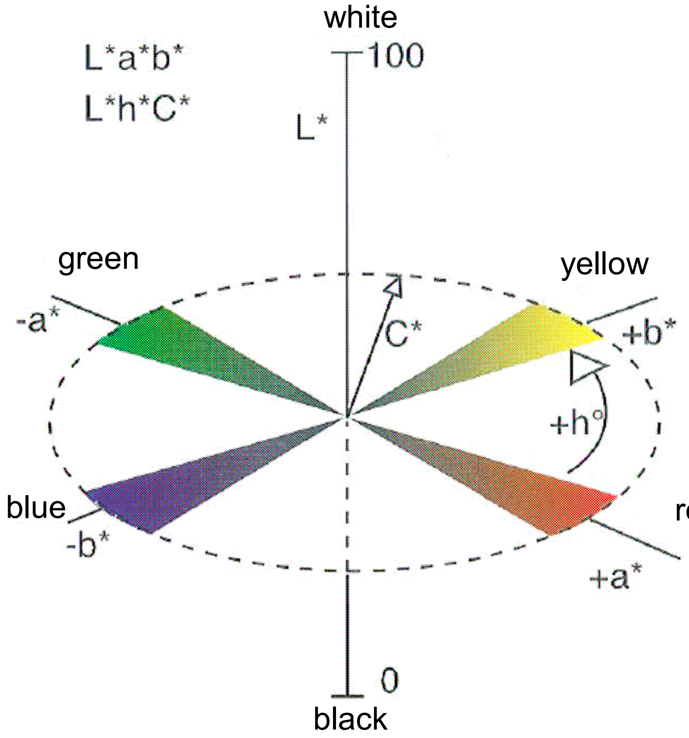


*Fig. 48 C.I.E.L*a*b* and L*h*C* space*

Main colour spaces and colour difference formulas which express DΔ with a single numeric index:

CIE 1964	**CMC (2:1), CMC (1:c)**
CIEL*a*b*1976, CIEL*h*C*1976	**CIE 2000**
FMC I, FMC II	**JPC79**

A big problem opposing colour reproduction is metamerism.
Two colours are metameric if they have equal coordinates in the colour space at certain observation conditions, and different coordinates if one of the observation conditions (see table enclosed to this Notebook) is modified.

What above occurs if the R% curves of the sample and of its imitation, although similar, are not superimposable.

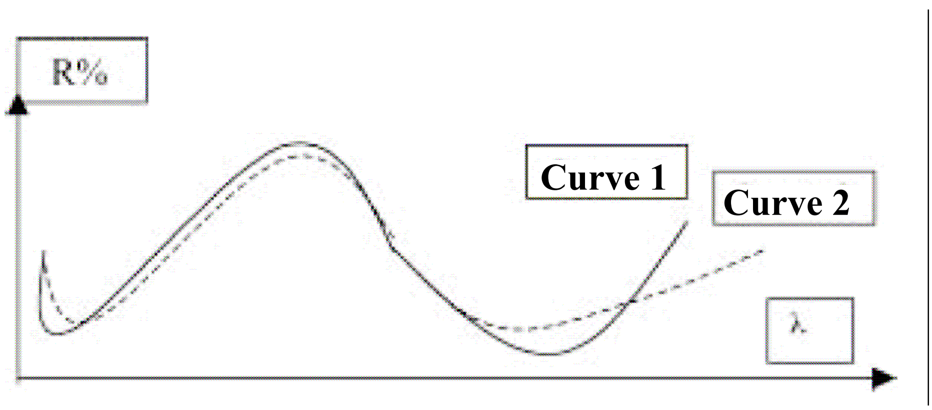


Fig. 49 Reflectance curves of metameric colours

The metamerism which is generally taken into consideration is the one pertaining to the illuminant, which occurs when a colour sample is reproduced with a dyestuff tern which is different from the sample colour. In case of instrumental recipe calculation, the metamerism index can be determined through a spectrocolorimeter, a determination which is not possible using a colorimeter.

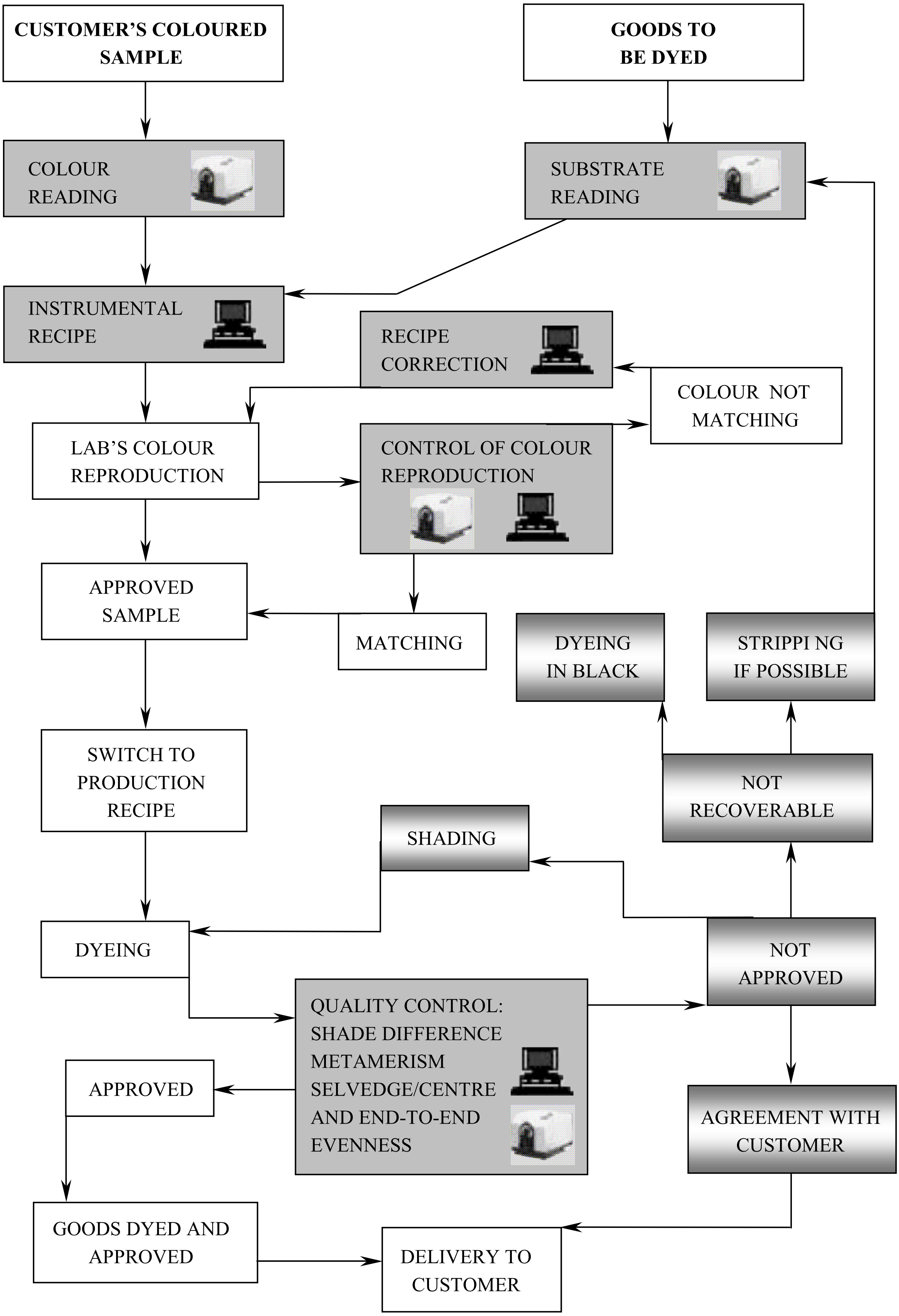
Instrumental recipe calculation, quality control and automation

As mentioned, the colours traced within the C.I.E. space are vectors and as such possess additive property, therefore they can be summed up and subtracted. If we sum two or more colours (vectors), we can calculate the colour which we shall obtain from their mixing. In particular, if we consider some factors which are related to the reflectance of dye molecules to the textile substrate and to the diffusion characteristics of the substrate itself, we can determine, through the **Kubelka-Munk (K/S)** relation and the **additive function ($F_{(R\lambda)}$)**, the outcome of a dyeing carried out with a certain dye mixture or, if we revert the problem, we can find through an instrumental recipe calculation system, the correct dyestuffs mixture to be used for the reproduction of a certain colour.
The use of an instrumental recipe calculation system requires:

a. a computer
b. a proper software
c. a spectrocolorimeter (or a colorimeter)
d. suitable database of colorimetric data related to dyeing trials (better if worked out within the company, but also data supplied by dyestuff producers are acceptable) on various substrates, separate according to single class of dyes, besides the colorimetric data of the substrares.

The theme of colour management will be dealt with more in detail in the chapter concerning automation.

COLOUR MATCHING CYCLE



DYEING

The dyeing process is aimed at giving woven or knitted fabric a definite colour which permits to customize the product.
The dyeing process can be carried out at different stages of fibre processing, i.e. in different forms: *staple*, *yarn*, *fabric (rope or open-width) and garment.*
When the dyeing process is carried out during the first processing stages, for example on staple fibres, a higher colour fastness can be achieved; bulk dyeing, which refers to the system used to dye a staple fibre before it is spun, is carried out in perforated baskets and possible uneven dyeings are levelled in a second time.
Yarn dyeing is carried out after twisting the fibres and is to be recommended for the production of jacquard or striped fabrics; this dyeing method ensures a good colour fastness, since the dye penetrates also into the core of the yarn. Hanks are dyed in cabinet machines, cones are dyed in autoclaves and warp yarns are dyed in perforated beams loaded in autoclaves.
Piece dyeing is carried out in several types of machines in open-width or rope. A good dyeing strictly depends on different parameters that can be evaluated immediately on the spot (such as good dye levelling and sample matching); it is however also necessary to comply with specific colour fastness requirements (during manufacturing, use, dry or wet processing) that can be controlled only through subsequent laboratory tests.
The machines used are chosen according to the material to be processed. The main requisites are the following:

- preservation of the substrate
- repetitiveness of the results
- cost-effectiveness of the process (depending on process time, machine automation level, goods/liquor ratio, cost of the products used and of waste water purification).

To carry out a dyeing process, it is necessary to:

- Dissolve or disperse the dye in an aqueous bath (with manual, semiautomatic and automatic colour kitchens according to specific preset rules).
- Feed the dye solution in the machine after suitable filtering (key factors: automatic colour kitchen, addition vats, pumps and filters).
- Transfer the dye from the bath to the fibre (key factors: process and machine).
- Distribute the dye homogeneously on the fibre (process and machine).
- Let the dye penetrate in the fibre structure and fix it (time and temperature).
- Wash or rinse the material to remove the dye on the surface or the unfixed dyeing liquor.

There are two different methods to transfer the dye from the liquor to the fibre:

Exhaust dyeing (discontinuous systems). The dye is dissolved or dispersed in the dyeing liquor. The material is immersed in the dyeing liquor and is removed only when most of the dye is transferred onto the textile to be dyed, is distributed homogeneously and is sufficiently penetrated into the fibre and fixed. At the end of the process, the material is washed or rinsed to remove the unfixed dye.

Pad dyeing (continuous or semi-continuous systems). This process is carried out using mechanical means (padding). The dyeing liquor, and therefore also the dye, is distributed homogeneously on the fabric.
In a second stage the dye penetrates into the material and is then fixed. At the end of the process, the material is scoured.

Following requirements are common to both methods:

- to dissolve or disperse the dye in water and to filter
- to achieve an homogeneous contact between the dyeing liquor and the fibre
- to make the dye penetrate into the fibre
- to fix the dye in the core of the fibre
- to carry out the final washing.

Exhaust dyeing

This process can be used for staple fibre, yarns and fabrics. The dye dissolved in the liquor is first adsorbed, i.e. the material is dyed only on its surface (dyeing result depends on the liquor turbulence), then penetrates in the core of the fibre (the dye diffusion is affected by temperature and dyeing time), and finally migrates, thus allowing uniform distribution and dyeing evenness (the process is affected by operating temperature and time).
During the process, kinetic and thermodynamic reactions interact.

Dyeing theory (exhaust dyeing)

The dyeing process is a chemical reaction occurring between the dye and the fibre:

$$\text{Dye(s)} + \text{Fibre} \underset{\text{V- 1}}{\overset{\text{V1}}{\rightleftharpoons}} \text{Dye - Fibre}$$

which can be studied in terms of kinetics (process speed) and thermodynamics (equilibrium state).

Kinetics and thermodynamics applied to dyeing

The dyeing process is in reality a complex chemical reaction, which occurs between the dye in solution and the fibre immersed in it. It is carried out in different stages (Fig. 50):

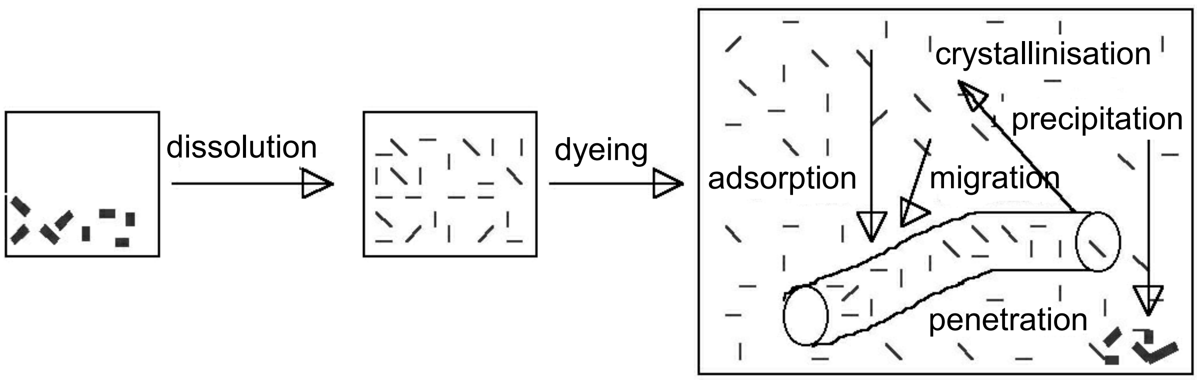


Fig. 50 Dyeing process stages

For a better understanding of the dyeing theory, it is fundamental to divide it into several stages (even if sometimes there is a time overlapping) and study each of them individually from various points of view:
Kinetics (study of the reaction speed)
Thermodynamics (study of the reaction equilibrium)
Hydrodynamics (influence on kinetics of the liquor and/or material turbulence, depending on the dyeing machine used). This aspect is important only for exhaust dyeing.

First stage (dissolution and dispersion of the dye)

In this first stage the dye, in solid form, is balanced with the dye dissolved in molecular or in micellar form (aggregates of many molecules with moderate solubility), or in form of dispersed micropowder (microcrystals of poorly soluble dye molecules) (Fig. 51).

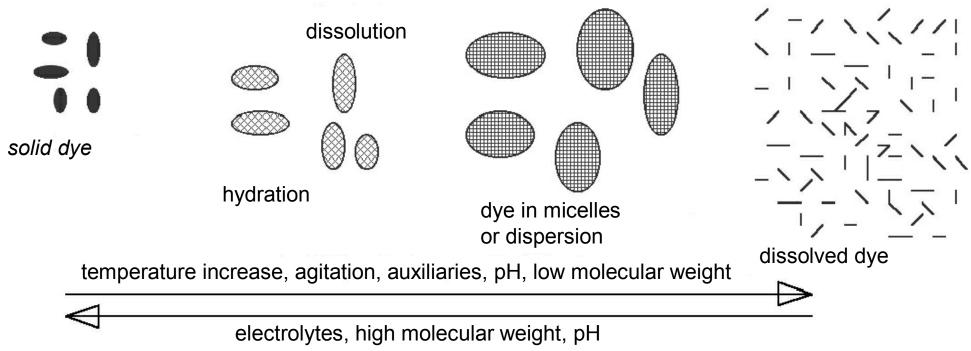


Fig. 51 Dispersion solution of the dye

As previously pointed out, dyes must be soluble or dispersible in water; it would be therefore suitable to make a distinction between soluble (a) and dispersed (b) dyes.

a) Ionic dyes can be divided into two main categories:
- anionic dyes, made of sodium salts of phenols, carboxylic acids, sulphuric esters, metallic complexes or, most frequently, sulphonic acids;
- cationic dyes, generally made of salts where the anion is chloride, sulphate, acetate or others, and the cation is the dye containing one atom of O, S or, most frequently, an atom of N with positive charge.

All these dyes create an equilibrium between the dye dissolved in molecules and the dye in micellar form (aggregates of several molecules with ionic groups partially salified and therefore provided with smaller unit charge); in this case, the solubility will depend on the ratio between the dimensions of the organic hydrophobic part and the type and number of hydrophilic groups: dyes with large-size molecules (high molecular weight) are generally poorly soluble; the presence of a higher number of ionic (sulphonic) groups, or the simultaneous presence of hydrophilic groups (hydroxyl, amino, amide groups, etc.), increases the solubility at same molecular weight. An increase of the temperature allows a quicker achievement of the equilibrium state and increases the solubility of the dyes (greater kinetic energy increases the disintegration of micelles).

Also agitation favours a quick disintegration of micelles. The addition of sodium salts (chlorides or sulphates) in large quantities increases the aggregation in micelles of anionic dyeing agents, thus reducing the solubility. Also pH can affect solubility; it increases the solubility of anionic agents in a basic environment and the solubility of cationic agents in an acid environment (owing to acid or basic dissociation constants).

Hard waters can produce precipitation of anionic dyeing agents, by formation of the respective insoluble calcium salts. An increase in the concentration of the solution dye (dyeing in deep shades, low liquor ratio) favours the aggregation in micelles. The speed at which the equilibrium between the solid dye-micelles and the dissolved dye (in standard dyeing conditions) takes place is generally sufficient, not to influence the dyeing speed.

Unsuitable conditions can cause precipitation and therefore originate uneven shades or reduce the exhaustion of the dyes.

b) Disperse dyes have an extremely reduced solubility (0.05-50 mg/l), which increases proportionally to the temperature. An equilibrium between dissolved and dispersed molecules is anyway produced (dispersed molecules are covered with a case made of dispersing agent molecules). Dyes with large-size molecules (high molecular weight) are less soluble in water; the presence of hydrophilic groups increases their solubility and dispersion capacity. Protective-colloid dispersing agents increase the stability of dispersions, which are generally more stable at pH 4-5. Excessive agitation (mechanical breaking of the case of dispersing agents), temperature variations (breaking of the bonds between the combination dispersing agent/dye or dispersing agent/water), long dwelling times (2-4 hours) at high temperatures, presence of electrolytes, can facilitate the aggregation of the molecules dissolved or of the small crystals, not coated with the dispersing agent, in bigger crystals, with consequent increase of the size of these last and their precipitation on the fibre and in the liquor.

Second stage (adsorption)

During this stage, because of the dye-fibre affinity, the dye is adsorbed at the surface of the fibre, thus forming chemical bonds with it.
Affinity, temperature, (sometimes pH and/or the auxiliaries) affect the thermodynamics (a) and therefore the equilibrium of the reactions, thus determining the exhaustion degree of the dyeing liquor.
The same factors influence also the speed in dye-uptake and therefore the uniform dye distribution. Obviously this fact conditions partly the dyeing speed which, during this stage, depends also on hydrokinetic factors connected with the machines used (b).

a) The affinity between the dye and the fibre is the ability of both to form between them a permanent bond. The higher the affinity, the stronger and more numerous are the fibre-dye bonds and the lower is the dye affinity for the solvent (water). Generally it is also directly proportional to the molecular weight (molecular size) of the dye. Affinity is therefore a factor strictly related to the chemical composition of the dye and of the fibre. This consideration applies also to the thermodynamic aspect. In general an increase of the dyeing temperature causes a change of the equilibrium towards the dye in the solution with a reduction of the exhaustion level and therefore a reduction of the dye-fibre affinity. In particular in the case of disperse dyes, considering the Nernst distribution coefficient, we have following equation:

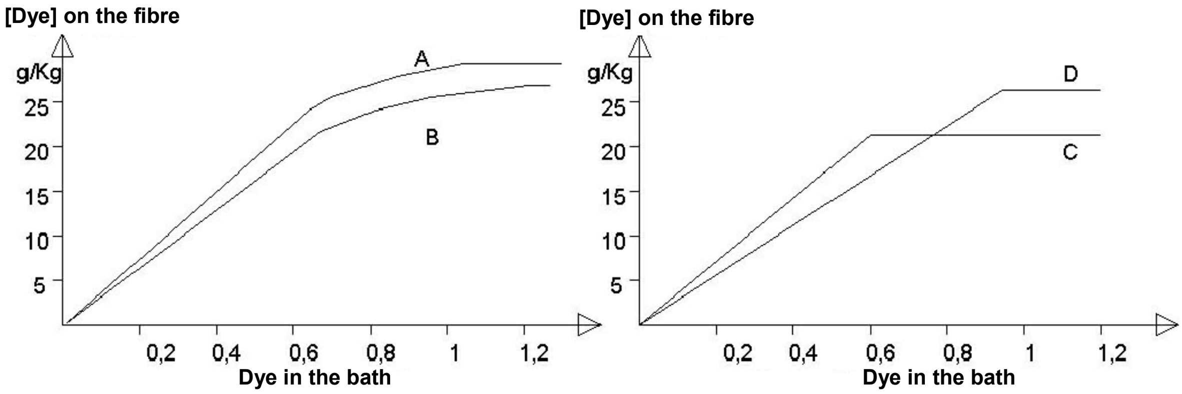
$$K(T) = C(f)/C(b)$$

C(f) is the maximum solubility (saturation value) of the dye dispersed in the fibres at T temperature.
C(b) is the maximum solubility of the dye dispersed in the dyeing aqueous solution at T temperature.
Both C(b) and C(f) get higher as T increases; as the temperature increases, the solubility in water increases more rapidly than the solubility in the fibre.

Therefore, at higher temperatures the saturation value of the fibre increases (the fibre absorbs more dye, so that deeper colour shades can be obtained), but the dyeing equilibrium moves in the direction of the solution dye, thus reducing the exhaustion level of the liquor (Graph 1 - A and B lines).
Since the dye that is adsorbed by the fibre is the one dissolved in molecules, the adsorption speed increases at higher temperatures.

Dyes with large-size molecules (high molecular weight) are less soluble in water, produce a higher number of bonds with the fibre and therefore, owing to temperature increase, exhaust the liquors more intensely and quickly than dyes with lower molecular weight.

Graphic 1 – Equilibrium between the dye on the fibre and the dye in the bath



IONIC DYES		DISPERSE DYES	
Curve	**Equilibrium conditions**	**Line**	**Equilibrium conditions**
A = T°1	T°1 < T°2	C = T°1	T°1 < T°2
B = T°2	T°2 > T°1	D = T°2	T°2 > T°1

For ionic dyes:

- Amphoteric fibres (wool, silk, PA) take below the isoelectric point positive charge, with an increase of the affinity towards anionic dyes; at pHs corresponding to the isoelectric point, they have zero charge, while above the isoelectric point they have negative charge and therefore reject dyes; this allows to accurately control the affinity and consequently uptake speeds and dye exhaustion, by suitably adjusting the pH value (Fig. 52). In the case of cationic dyes, the affinity changes in the opposite direction.
- Cellulosic fibres in neutral environment take negative electrostatic charges, thus reducing the adsorption of anionic dyes; the addition of electrolytes to the solution permits to neutralize the negative charges on the fibres by the adsorbed cations, thus facilitating the adsorption of the dyes (Fig. 52).

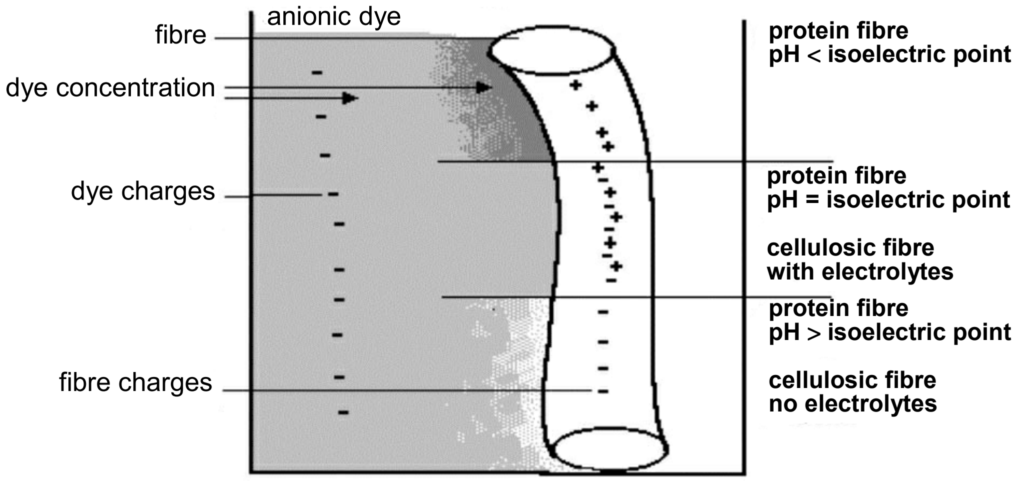
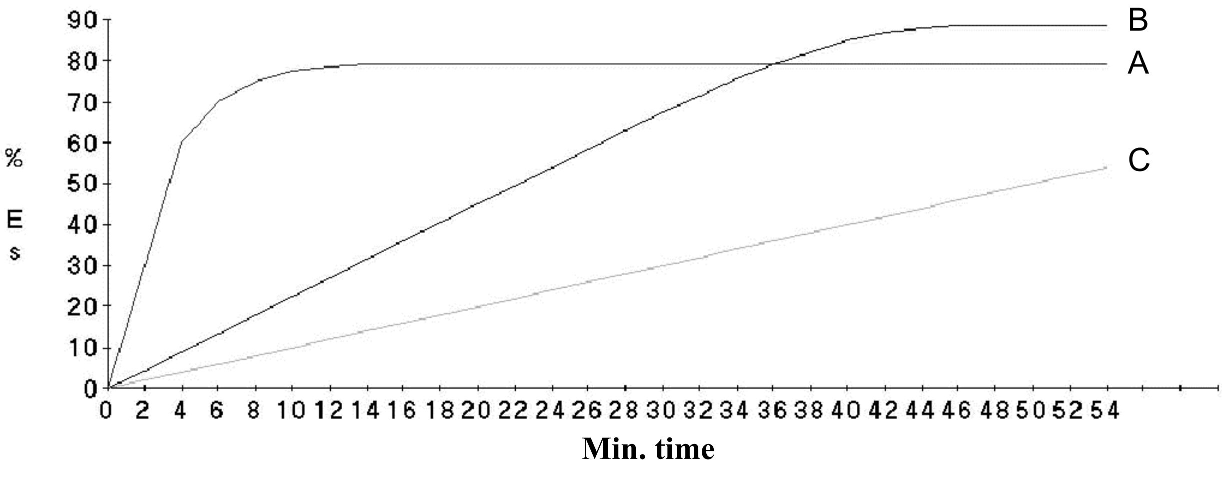


Fig. 52 Dye concentration in the bath next to the fibre

- Dyes with large-size molecules (high molecular weights) are less soluble in water, form more bonds with the fibre and therefore tend to exhaust liquors more quickly.
- With ionic dyes, contrarily to disperse dyes, the saturation point of the fibre is reached gradually, and therefore the relationship between the dye concentration in the liquor and that on the fibre is no longer linear.
  High temperatures reduce the dye-fibre affinity and also the exhaustion level (Graph 1 - C, D curves), but the adsorption speed will be higher (Graph 2)

Graph 2



CURVE	T°	Exhaustion speed	Exhaustion %
A	High	Too high	Poor
B	Medium	Correct	Good
C	Low	Too low	Excellent

During this stage, the exchange between the material and the liquor, and therefore the hydrokinetic condition (motion of the liquor in respect to the material to be dyed), plays a very important role.
The most favourable conditions are created with machines where both the material and the liquor move, with a low material/liquor ratio (more cycles/min. of the liquor with the same pump flowrate).

A quick adsorption of the dye on the surface of the fabric reduces the dye concentration near the fibre, thus lowering the adsorption speed. A correct speed of the liquor change in contact with the fibre allows to maintain the maximum concentration of the dyeing solution near the fibre, and consequently the correct speed. (Fig. 53).
At the same time, the liquor flow in contact with the material is spread homogeneously and allows a good statistical distribution of the dye in all the areas of the textile surface; this enhances the dye consistency with the same operating times.
The adsorption reaction is usually sufficiently quick not to affect the dyeing speed, and often needs to be slowed down or anyway adjusted (T°, pH, auxiliaries) to optimum values, in order to avoid an irregular distribution of the dye.

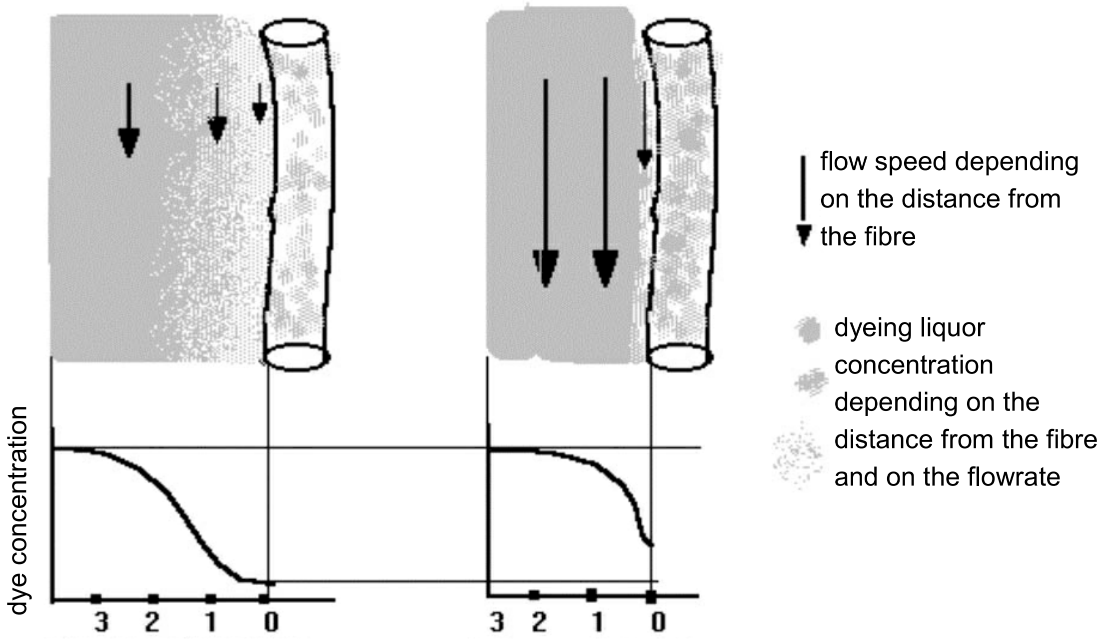


Fig. 53 Dye concentration in the bath next to the fibre depending on the hydrokinetic factor

Third stage (Diffusion)

During this stage the dye, adsorbed in molecular form by the surface, tends, by breaking and restoring the bonds many times, to penetrate into the bulk of the fibre through amorphous areas, to spread homogeneously and fix steadily.
The slowest stage of the dyeing process is extremely important, since it sets the times for a good penetration, essential for optimum fastness, and consequently for good cost-efficiency and excellent quality.
Fundamental factors are:
- Crystallinity of the fibre: the dyes penetrate the fibres through amorphous areas and therefore the higher the crystallinity, the lower the diffusion speed.
- Molecular size of the dye: the bigger the dimensions of the dye molecules, the more difficult the diffusion through amorphous areas.
- Strength of dye-fibre bonds (affinity): the stronger the bond, the more difficult the diffusion.

- Dyeing temperature: the temperature increase facilitates the breaking of dye-fibre bonds and releases the intramolecular bonds of the fibre. This leads to a swelling of the fibre and makes the diffusion quicker, but simultaneously reduces the affinity and therefore the exhaustion level (Fig. 54).

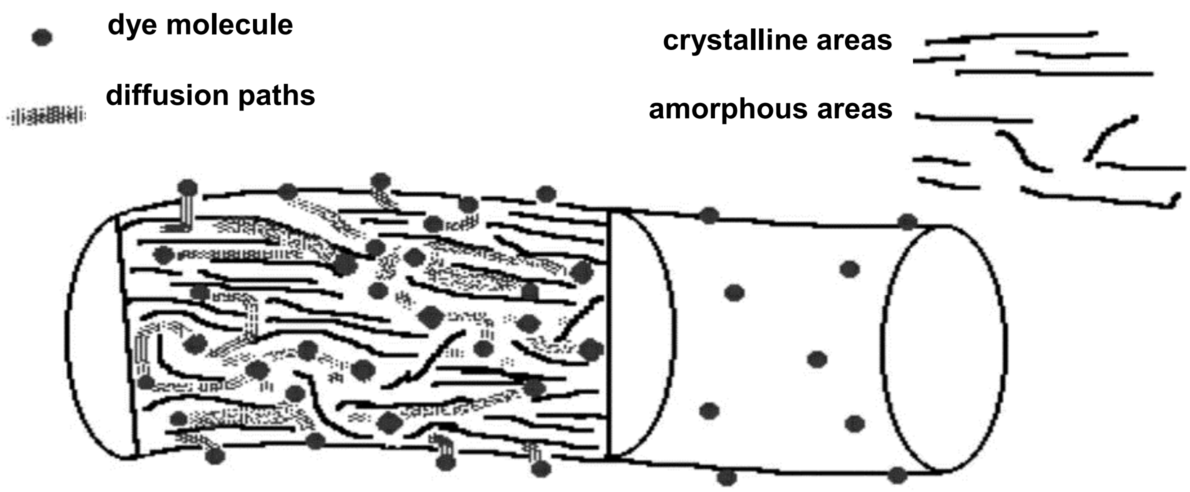


Fig. 54 Scheme of dye penetration and migration

A higher concentration gradient accelerates the diffusion: the maximum dyeing speed can be obtained only by keeping the fibre surface saturated with dye (thus keeping the highest possible concentration gradient), by means of a suitable exchange speed of the liquor on the surface of the fibre (hydrokinetic condition - Fig. 53).
The presence of auxiliaries, facilitating the fibre swelling or increasing the concentration of dye near the fibre (swelling agents), tends to increase the diffusion speed.

The operating time must be sufficient to allow a good penetration of the dyes, since this is a prerequisite for developing the maximum shade fastness (Fig. 55).

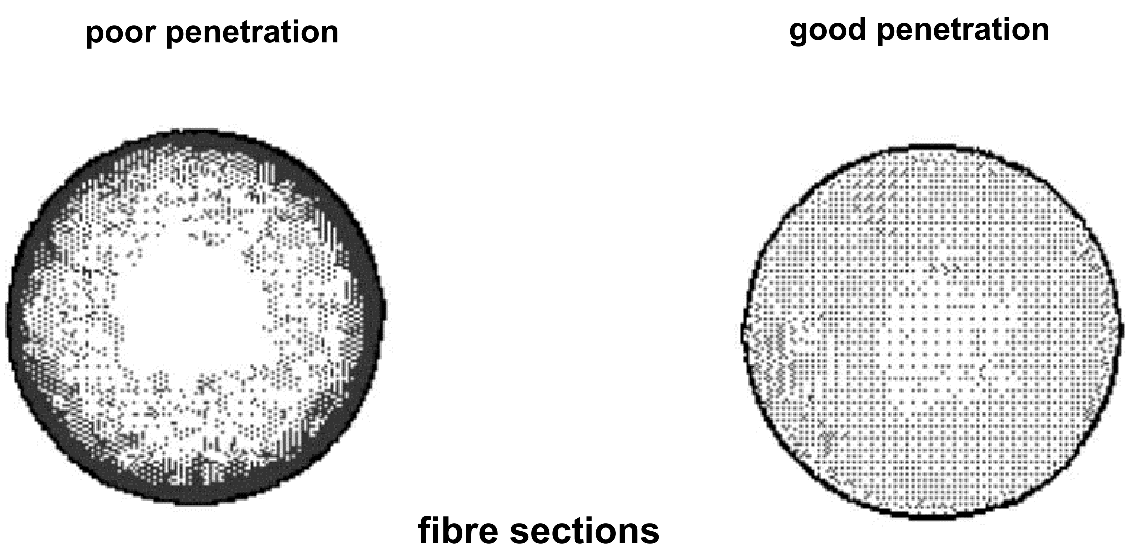


Fig. 55 Dye penetration

Fourth stage (migration)

Stages 2 and 3 are reversed in this fourth migration stage; the dye must diffuse toward the external layers of the fibre, and then come back always in solution and migrate in areas of the fibre, where there is a lower concentration of dye, thus enhancing colour evenness.
Low affinity, poor crystallinity of the fibre, small molecular size of the dye will favour this stage, though negatively affecting colour fastness and liquor exhaustion. On the other hand, a high concentration of electrolytes would facilitate the aggregation of anionic dyeing agents, above all in the core of the fibre where the dye is more concentrated, improving the exhaustion and reducing the migration phenomenon.
Migration is facilitated by long dwelling times at high temperatures, which leads to higher costs; a good control of the adsorption and diffusion stages, with a smooth dispersion of the dye in every moment of the dyeing process, can make the migration stage superfluous, with a subsequently higher cost efficiency and quality.
For disperse dyes, considerable thermal variations and lack of suitable colloid-protective dissolving agents can cause the growth of the dye crystals, which lay on the material or precipitate, originating dyeing defects and low fastness to rubbing. An excessive agitation (pumps), or a wrong pH, can cause instability of the dispersion.
Anionic dyes tend to precipitate at excessively low pH values and also in the presence of hard water or large-size cations; cationic dyes could precipitate in neutral or basic environment and in the presence of large-size anions.

Pre-dyeing and dyeing machines

There is a wide variety of machines used for finishing processes (pre-dyeing, dyeing and finishing treatments).
As far as dyeing machines are concerned, the most important aspect to be considered is the uniform distribution of the dye (or of other chemicals) that the machine must ensure in the shortest possible time. Generally, the systems allowing a homogeneous distribution of the dye also allow a good removal of dirt and a uniform contact of bleaching reactants with the material; therefore what we say about dyeing, in most cases can be also applied to pre-dyeing and finishing treatments that require the application of chemicals.
The machines used for preparation and dyeing processes can be classified as follows:

A - Classification according to the textiles to be processed:

The machines to be used are chosen according to the type of material to be processed.

- Machines for dyeing staple or yarn (in hanks, cones or beams)
- Machines for dyeing woven/knitted fabrics in the rope (the fabric width is not opened)
- Machines for dyeing open-width fabrics (the fabric width is opened and flattened)
- Machines for dyeing made-up garments.

B - Classification according to the processing method:

The machine to be used depends on the quantity of materials to be processed and on the type of finishing process.

- Machines for discontinuous (batch) processing
- Machines for semi-continuous processing

- Machines for continuous processing

C - Classification according to the operating principle:

The machine to be used depends on the composition of the material (fibre and weave), as well as on the type of treatment to be carried out.

- Machines with liquor circulation
- Machines with material movement
- Machines with both dyebath and material movement

D - Classification according to the process conditions:

The system to be used depends on the type of material (fibre form) and on the process to be carried out:

- Machines that can work under pressure at high temperatures (HT autoclaves)
- Open machines or machines running at max. temperature 100°C.

Here below the reader will find a brief description of the (A) category; each machine is described in detail hereafter.

Machines for staple, sliver and yarn processing

These machines are used for dyeing staple fibres (and also for carrying out other treatments such as bleaching, scouring or finishing) and more frequently for dyeing yarn fibres in different forms (cones, cheeses, etc). With the use of modular and interchangeable carriers, it is possible to carry out loading and dyeing processes using cones of different diameters. These machines are equipped with automated systems, such as automatic loading and unloading racks positioned above the machine, centrifugation and drying systems, to satisfy in the best way the growing demand for system optimisation.

Open-width dyeing machines

These machines are used for dyeing open-width and well flattened fabrics.
These machines can be used also for carrying out pre-dyeing treatments (for example scouring, bleaching, mercerizing), dyeing treatments and wetting operations.
Among the machines used for open-width treatments, we can mention mercerizing machines, jiggers, pad dyeing machines, beam dyeing machines, continuous washing lines, stenters.

Rope dyeing machines

These machines process the fabric which is fed and driven lengthwise to form a rope. The hydrodynamic effect is obtained by the motion of the fabric rope, or by means of the simultaneous rope and dyebath motion, which ensures a homogeneous contact of the material with the dyeing liquor and a quick exchange of the dyeing liquor dispersed in the material. Machines running according to these operating principle are suitable for treating almost all the fabrics in all kinds of fibres, woven or knitted, during preparation and dyeing stages, with only some problems occurring with loose-weave fabrics. During the treatments, the fabrics run freely weft-wise and therefore can freely shrink and set, thus eliminating almost all tensions. Suitable operating conditions and

technical adjustments also reduce to the minimum warp-wise tensions and continuously move the wrinkles of the rope.
An unquestionable advantage obtained with these machines is the extremely soft and fluffy hand, particularly suitable for fabrics to be used for garments.
Possible problems are the formation of permanent wrinkles on the fabric or the production of uneven shades; in case of fabrics made up with very delicate or short staple fibres, mechanical stresses can cause the losing or extraction of the superficial fluff.

Garment dyeing machines

These are discontinuous processing machines; the most modern machines are equipped with rotating systems, which apply low liquor ratios; the material is packed in a perforated basket, which rotates at variable speed. Once the dyeing process has been completed, the excess liquor is removed from the fabric by centrifugation before unloading.
These machines are equipped with automated devices to optimize the process.

Autoclaves

These machines are used for dyeing staple and yarns in different forms (cones, cheeses, beams, etc.).

These machines are essentially composed of:

- Vertical or horizontal autoclaves, made of stainless steel, where interchangeable carriers are placed for dyeing different textiles at any stage of their development (baskets for staple dyeing, cone carriers, cheese carriers, warp beams, etc.)
- Circulating liquor pump (with flow reversal system)
- Expansion vat to compensate the increase in liquor volume, where the necessary dyes and auxiliaries can be added without stopping the operating cycle.
- Static pressure pump (which can be introduced at any operating temperature)
- Sample heater
- Control board for partially or completely automated dyeing cycle.

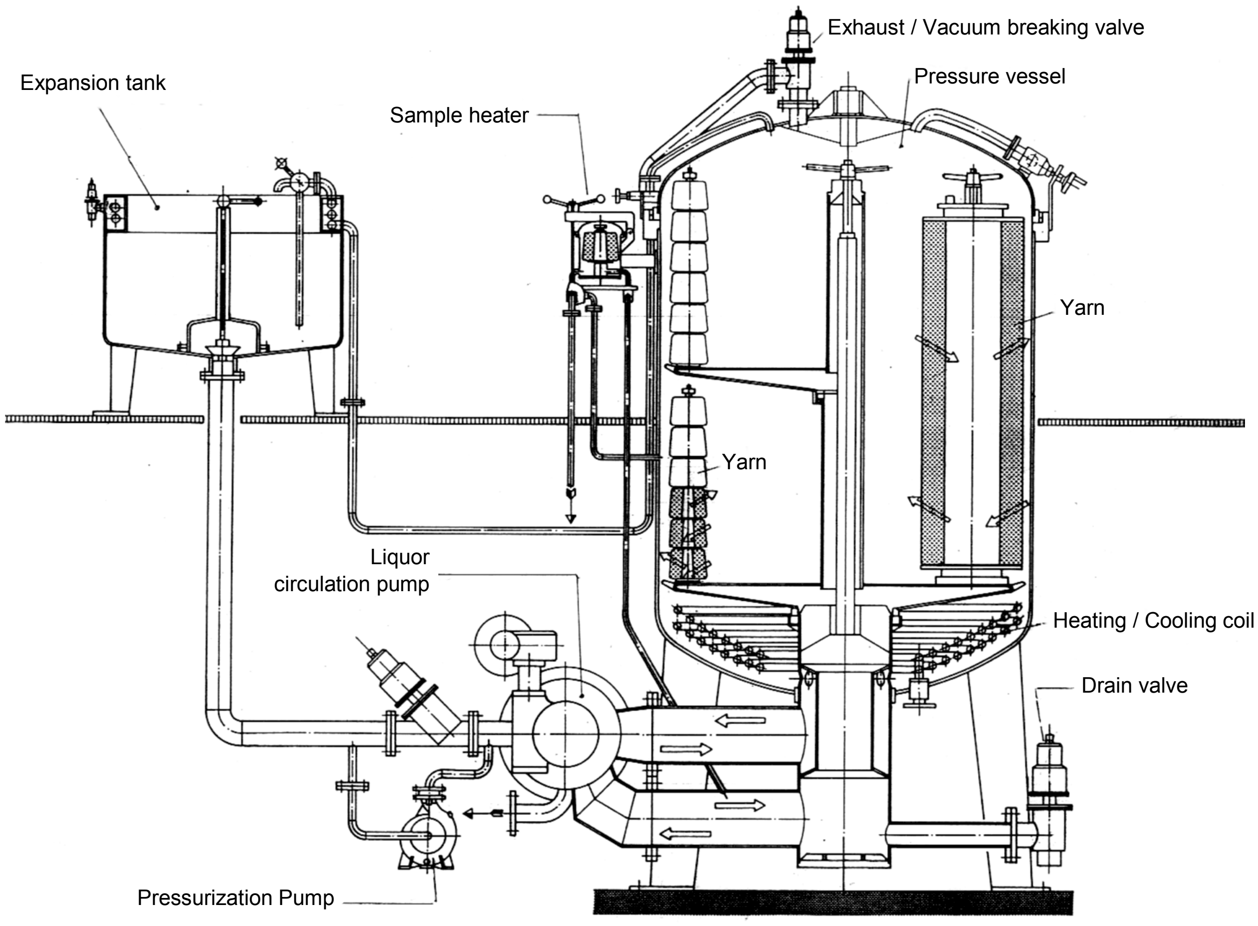


Fig. 56 Vertical autoclave (cross-section)

All manufacturers are today in a position to supply these machines equipped with microprocessor or PLC programming system for controlling and setting all the operating functions (filling, exhaust, heating, cooling,, dosing, etc.) of the whole production cycle and, in specific cases, for adjusting the pump flow according to preset parameters.

** Some parts and illustrations of this chapter have been taken from the book "Nobilitazione dei Tessili" by Franco Corbani, published by Centro Tessile e Abbigliamento in (1994.*

We can distinguish between vertical autoclaves, which are better suited to companies with poor floor space available (Fig. 56), and horizontal autoclaves, which are more convenient as to loading/unloading modalities (Figs. 57 and 58).

Fig. 57 Horizontal autoclave with bobbin carriers

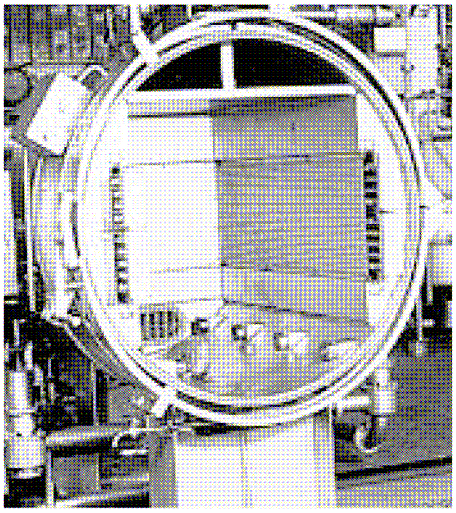


Fig. 58 Front view

The problem of flexibility in the loading capacity, independently of the machine type used, as well as the maintenance of a constant liquor/goods ratio, was solved initially with the use of proper expansion tanks (volumetric pressure reducers) which were inserted into the machines in place of the missing material.

Subsequently the same result was obtained with the air-pad method: the bath covers the goods, while a superimposed pad of pressurized air offers the possibility of operating with variable loads while maintaining unchanged at optimum values the bath/material ratio. This system permits also to reduce the energy consumption and to eliminate the expansion tank (see machine and relative material carriers in Fig. 59).

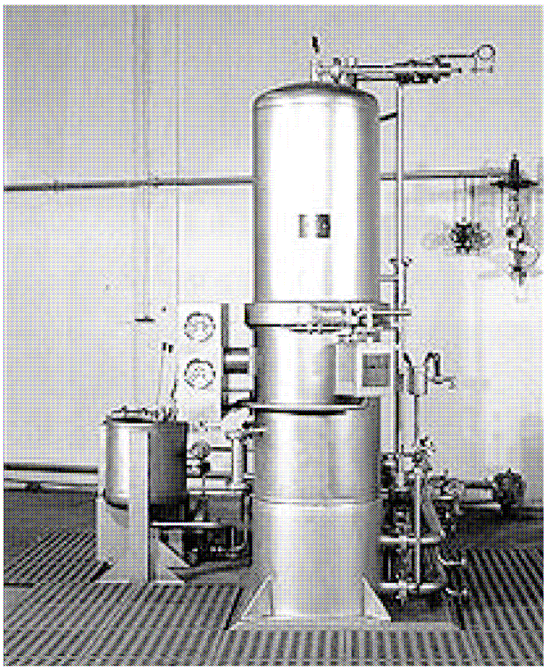


Fig. 59 Vertical autoclave for variable loading and relative cones carrier

Another structural version of modular machine used only for yarn packages includes, instead of a single heated vat, many small horizontal heaters of variable sizes which can operate independently from each other, permitting to dye several lots in different colours; in alternative, the heaters can be interconnected, which permits to dye in just one colour a large-sized lot (Fig. 60).

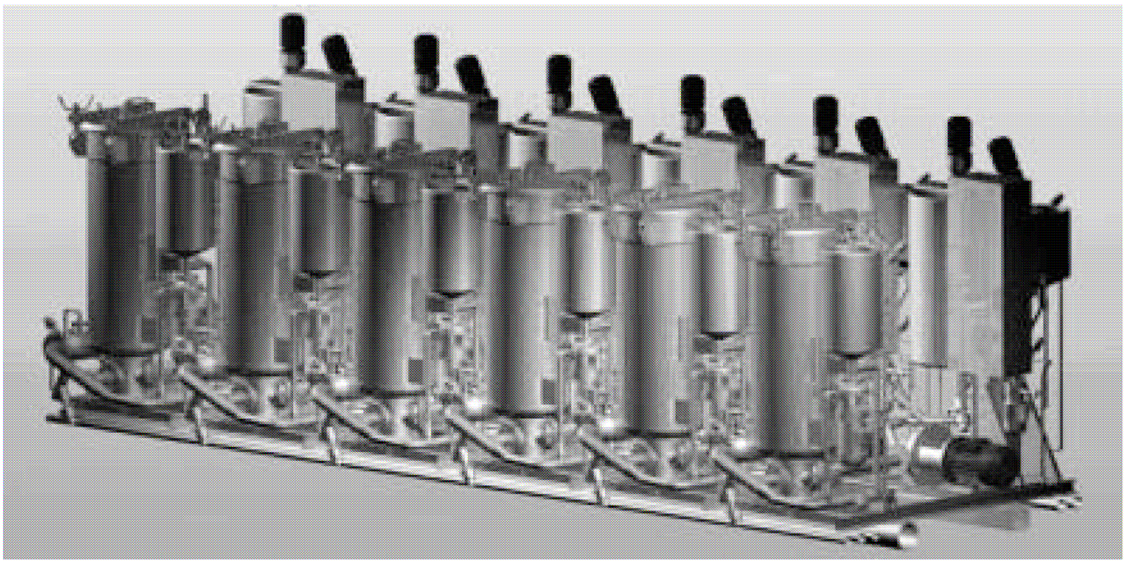


Fig. 60 Modular machine

The material to be dyed must be always arranged accurately, to avoid possible disproportion in the passage of the liquor, which is forced under pressure through the material alternately in both directions, from the core to the outer surface and viceversa, according to programmable times (for example from 2 to 4 cycles per minute).

Fig.61 Horizontal autoclave for cones

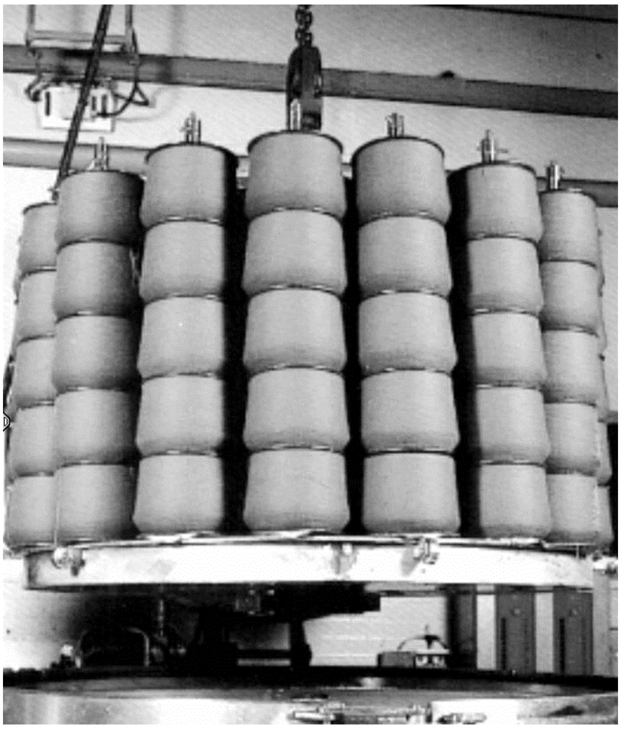


Fig. 62 Bobbin carrier

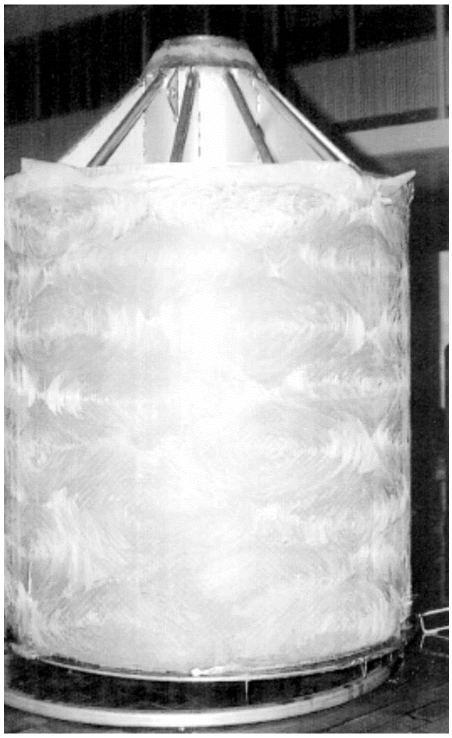


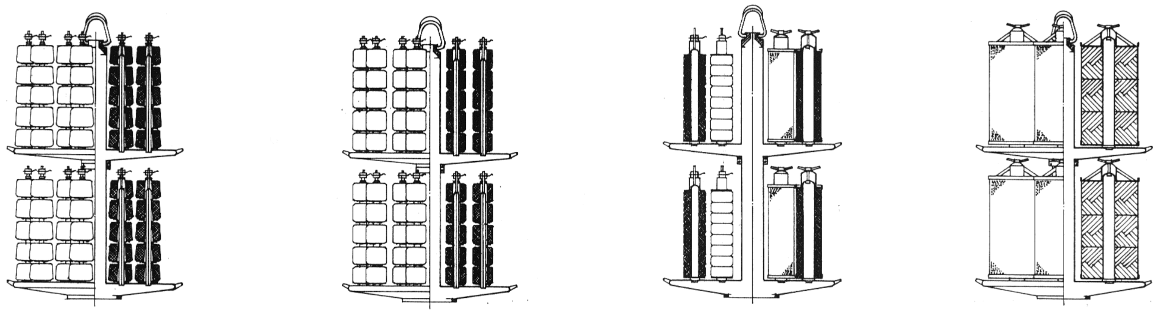
Fig. 63 Staple fibre carrier

In all these autoclaves, the dyeing liquor is kept circulating by means of centrifugal or helical pumps: these pumps must keep the liquor circulating through the mass of fibre, so that the fibre surface is saturated with the dye. To do that, the liquor must overcome all the resistive forces generated by pipes and by the textile mass (pressure drop) and reverse the direction of the liquor circulation at different times to obtain an overall even colour; in specific cases, the speed of the pump impeller can be set by means of inverters (frequency inverters), which adjust the flow of the liquor through the fibre mass.

These machines, built and tested according to the European PED standards, can operate at a maximum pressure of 5-6 bar and are statically pressurized by means of a pump or of a compressed air pad; they are suitable for treating synthetic fibres up to an operating temperature of 145°C, avoiding load-carrying drops due to cavitation of the liquor circulation pump. The average liquor ratio is approximately 1:10.

Automated dyeing cycles grant excellent quality and reproducibility of results. Some autoclaves also integrate dyeing, centrifugation and drying systems. These machines, used for dyeing various types of fabrics or blends, can also be employed for scouring and bleaching tasks.

We describe below several carriers made of two superimposed levels, which can be separated for easier loading and unloading. In fact these machines, besides with cones, cheeses, tops, etc. (which can be loaded in single-level machines or in machines equipped with horizontal boiler), can be loaded with fabric beams; they also allow cutting the loading capacity in two (see schemes of the different material carriers), thus increasing the operating flexibility.



Cones   Cylindrical packages   Cheeses   Tops

Fig. 64 Various types of two-tier material carriers

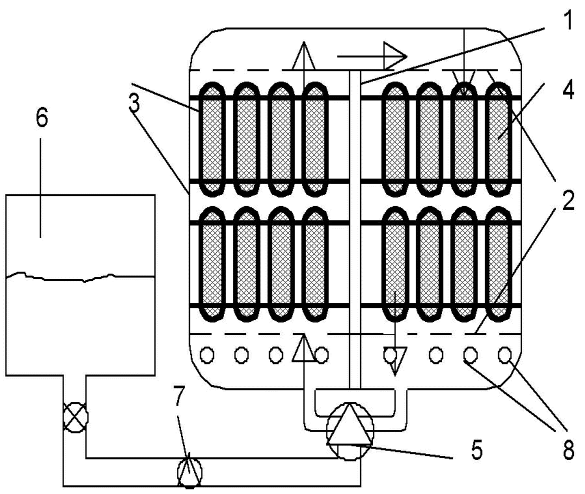
With reference to the schemes above, we only need to add some detailed information about cone yarn dyeing. This dyeing system is more popular than staple and hank dyeing (cheeses are no longer used), since it is more cost-efficient and environment friendly.

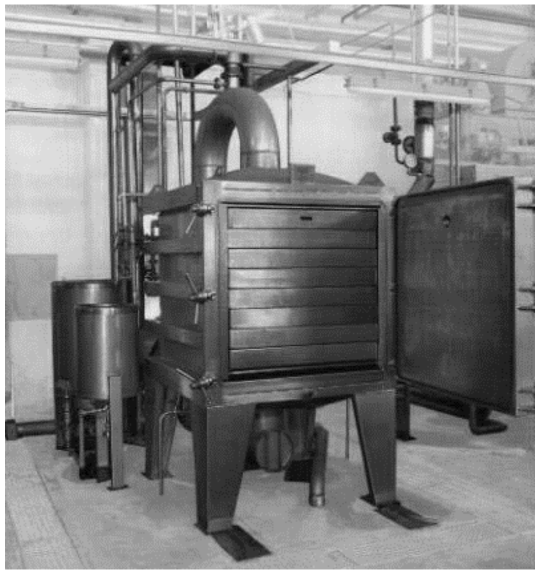
The diameter, and therefore the weight, of each single package greatly varies according to the type of fibre, to the count, to the final use and to the different classes of dyestuffs used. Cones can be prepared by winding the yarn on perforated tapered or cylindrical tubes of different height and diameter; the weight can range between 700 grams for very fine cotton yarns for shirts and knitted goods and 3.5-4 kilograms for large polyester packages.

The dyeing sector has recently undergone a very incisive improvement in automation and robot control. In particular, the handling of the packages is reduced to a minimum; simple and reliable robots load and unload the package carriers and carry out the subsequent dehydrating step by means of automatic hydroextractors and drying by means of fast dryers with forced air circulation or high-frequency heated tunnels (see chapter on drying).

Cabinet machines

Cabinet machines are used for hank dyeing; a cabinet machine is made up of a parallelepiped-shaped vat divided into compartments by perpendicular partitions. The hanks are arranged on special carriers, which can be locked in special grooves inside the machine; the liquor circulates in both directions (up-and-down flow) and the yarn mass makes only a moderate resistance since it not very tightly packed.
The machine operates with reduced liquor ratios and the liquor itself is kept circulating by means of major flow axial pumps (suitable for delicate yarns), assembled in the front part of the machine.
The liquor flow inversion is obtained by reversing the rotation direction of the motor; the liquor is generally heated by means of serpentines assembled inside the machine or by means of heat exchangers. The hank can also run under pressure at a maximum temperature of 110°C and at pressures of 0.5 kg/cm^2. If the pressurisation is obtained by means of an air pad, it is possible to avoid the external circulation of the liquor in a lateral extension vat.
As a result, the liquor can be maintained at a constant temperature, reducing energy, steam and cooling water consumption.
The only negative aspect is the need to unload and load the machine each time it is used. Hanks can also be used for washing and bleaching treatments.





1 central wall; 2 perforated separators;
3 perforated supports; 4 hanks; 5 circulation pump; 6 addition vat;
7 auxiliary pump; 8 serpentines.

Fig. 65 Scheme and picture of a cabinet machine

Arm machines

This is the most suitable machine for dyeing delicate yarns (silk, cupro Bemberg, etc.) ., since it prevents the material from being too tightly packed as it happens with other hank dyeing machines. The machine is equipped with horizontal arms perforated in the upper part, on which hanks are suspended. The liquor, forced through the arm holes, penetrates into the hanks and is then collected in an underlying vat. Standard machines are equipped with a rod (turning rod) which moves the hanks at preset times, changing their bearing point to obtain a more uniform dyeing. During hank motion, the flow of the liquor is stopped to avoid the formation of tangles in the yarn; since yarns are not fixed to rigid supports, they can thoroughly shrink. This machine does not run under pressure. It is possible to dye at constant temperatures, since the liquor is contained in a separate tank.
The operating costs of this machine are generally very high because it requires a very high liquor ratio (1:15 – 1:25 – 1:30).
Standby times for loading and unloading operations are also very high and the arms must be often cleaned. This machine can be used also for scouring and finishing processes.
Some machine manufacturers have designed machines with slant covers to avoid unwanted liquor dripping on the hanks; the hank rotation is determined by the perforated arms, and not by the rotation of the hank-lifting device when the arm is stopped; it is therefore possible to eliminate the sliding contact with the hanks and preserve them perfectly.
There are also hank dyeing machines with triangle-shaped arms, arranged radially on a variable speed rotor. When the dyeing process has terminated, the material can be centrifuged and dried by forcing a hot air flow into the arms and through the hanks.

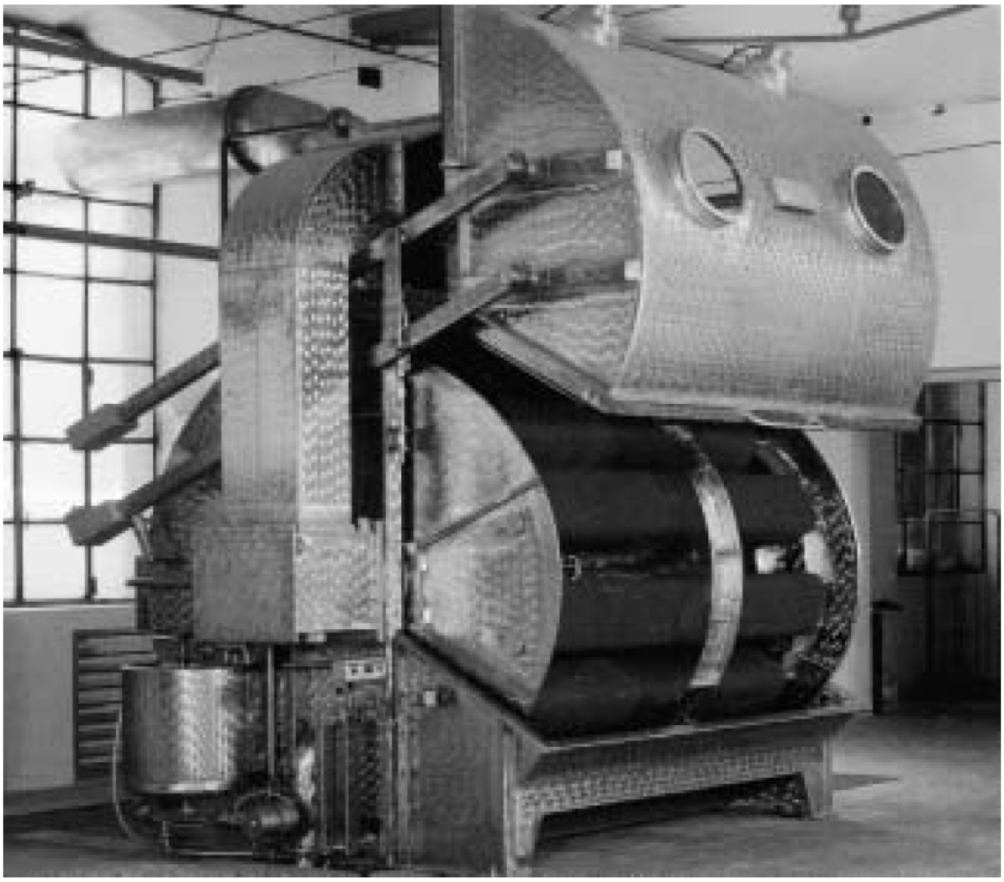
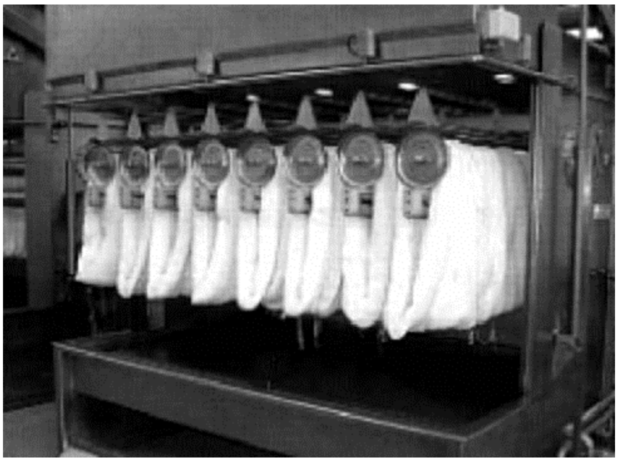


Fig. 66 Arm machine with triangle-section arms



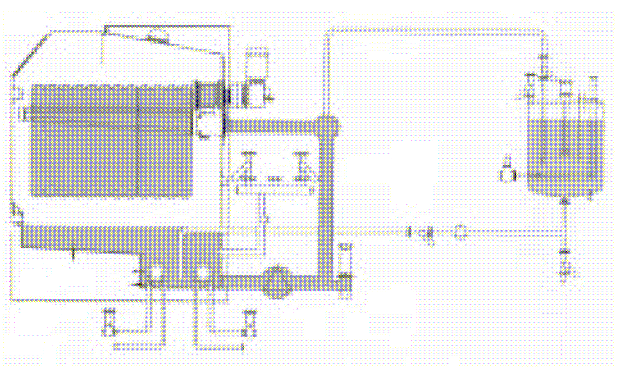
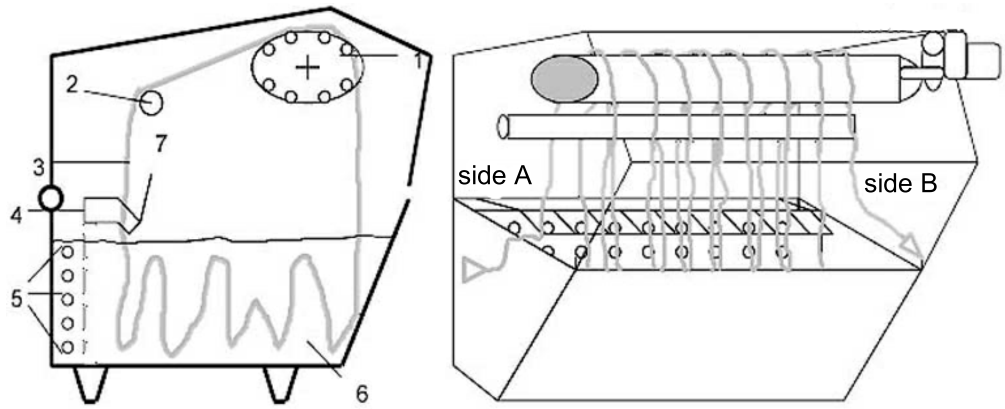


Fig. 67 Modular hank dyeing machine with pullout arms.
Pullout arms allow the loading and unloading of the hanks also far from the dyeing machine, without any manual intervention in the intermediate dyeing, squeezing and drying operations. It can be used for silk, cotton, viscose and cashmere yarns.

Winch machine

This is a dyeing machine of old concept for the dyeing of fabrics in rope form with stationary liquor and moving material. The machine operates at a maximum temperature of 95-98°C. The liquor ratio is generally quite high (1:20-1:40).
The system includes a vat with a front slant side acting as chute for the folded fabric, while the rear side is entirely vertical. A perforated separating section, positioned at a distance of 15-30 cm from its vertical side, creates an interspace for heating and for adding reagents. Heating can be supplied by means of direct or indirect steam.
The fabric motion is driven by a circular elliptic winch coated with a special blanket to avoid the fabric slipping during the dyeing operation with subsequent possible fabric scratches.
Afterwards the rope to be dyed passes through a rack on the vertical perforated divider, which ensures the separation of the various folds of the rope and avoids possible entangling; the rope is then transferred onto a cylinder, which guides the fabric during the lifting from the vat, carrying out a partial squeezing with subsequent liquor exchange. The rope (carried by the winch) folds while passing through the liquor. Obviously, when the fabric is loaded into the machine, it is necessary to sew one end to the other end of the rope (the fabric must be sewn according to the grain direction).
The maximum motion speed of the fabric must be approx. 40 m/min., since higher speeds could cause peeling; an excessive stretch during the lifting stage could cause deformation, while high circulation speed could cause excessive rope beating with subsequent entanglement. The fabric must not remain folded and kept stationary inside the vat for more than 2 minutes, to avoid possible defects or wrinkles; therefore the rope must be relatively short.
The winch dyeing method is suitable for all fabrics, except those which tend to originate permanent creases or which could easily distort under the winch stretching action (due to their fibre or structure composition).
This machine is used preferably for pre-dyeing treatments (scouring, washing, bleaching), since the high liquor ratio ensures excellent results; when used for dyeing treatments, this machine requires high energy consumption and extensive use of auxiliaries, dyes and water, which leads to high operating costs; furthermore, an inaccurate temperature control (the liquor does not move and the heating system is assembled only on one end) and the limited movement possibility of the rope folds could negatively affect the dyeing results.

Although one of the oldest machines used for finishing treatments, this machine proves to be still extremely functional thanks to its flexibility, above all for scouring and bleaching treatments to be carried out on small production runs. This system can also be used for carrying out continuous washing processes; the fabric is loaded from one side (A side, Fig. 69), driven through the machine with a spiral motion (by means of the rack) and then unloaded from the opposite side (B side).



1 – Winch
2 – Guide cylinder
3 – Fabric rope
4 – Perforated separator
5 – Heating coils
6 – Liquor
7 – Rack

Figs. 68 and 69 Schemes of a winch dyeing machine

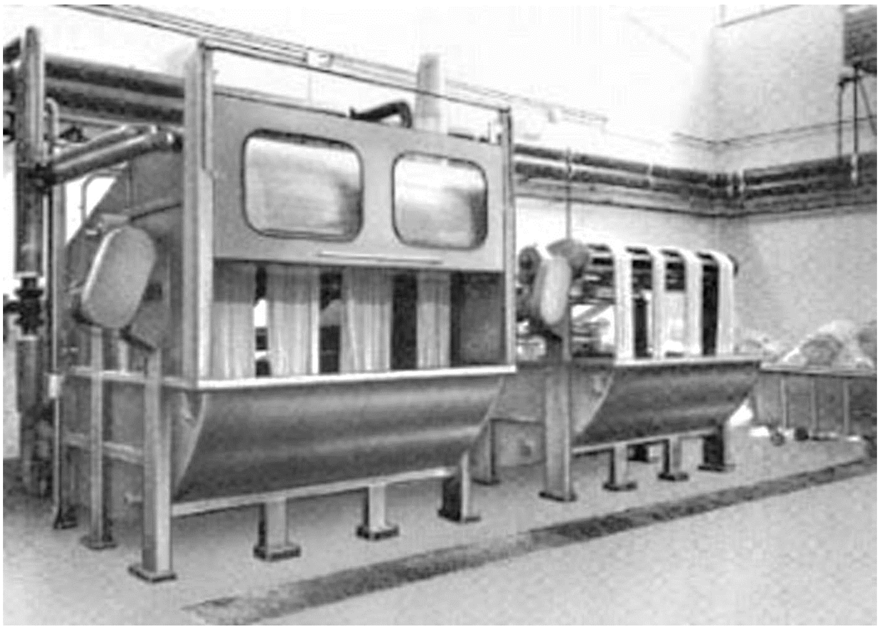


Fig. 70 Winch dyeing machine

Jet machines

These machines, in which both liquor and material move, are used for rope dyeing and dyeing pre-treatment; the fabric is carried over and driven through the machine only by the fluid force. These systems run with high temperatures (maximum temperature ranges between 135 and 140°C), with very limited liquor ratio (1:5-1:15).
We can divide these machines into different categories: for example, there are machines only partially filled with liquor which are suitable for treating PES or PA and synthetic filament fabrics, and on the other hand machines completely filled with liquor, which are used for more delicate fabrics (the fabric is carried over more delicately and is always immersed in the liquor). Now the trend is for the production of machines with more delicate fabric drive, which adds to the hydraulic drive of the jet system a mechanical drive carried out by means of a large-size reel; this makes this multi-purpose system more flexible and therefore suitable for treating an increasingly wide range of fabrics.

Partially filled jet machines (Fig. 71): The external part of the machine consists of an autoclave, generally horizontal and cylinder-shaped, with a turret on one side, provided with an access door and glass window; the jet nozzle from which a tube starts is usually assembled inside the turret. The tube passing over or under the autoclave fits on the opposite lower side of the autoclave, thus assuring a continuous connection.
The folded rope fabric moves slowly in the autoclave inside a special vat, partially immersed in the liquor, till it reaches the lifting compartment (the turret). Inside the turret, the rope is lifted up and, running on an idle or power-driven cylinder (reel), is immersed into the jet nozzle. The rope moves along the return tube and is sent back (folded) to the opposite side of the vat, to begin the cycle again.
The liquor circulated by means of a centrifuge or axial multi-step pump passes through a heat exchanger before being sent to the jet nozzle.

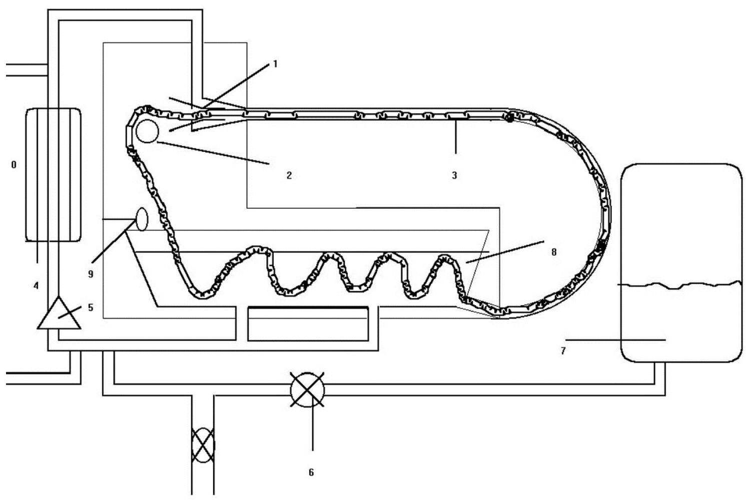


Fig. 71 Scheme of a jet machinewith partial filling

1- jet	*6- auxiliary pump*
2- guide roller	*7- addition vat*
3- transport tube	*8- fabric and dwelling vat*
4- heat exchanger	*9- magnet signal system*
5- liquor circulating pump	*10- by-pass valve*

The outer part of the jet transport system (applying the Venturi principle, see Fig. 72), is composed of an external funnel for fabric passage, assembled in a position coaxial with the tube; the liquor, forced through the tube with a specific pressure, is progressively accelerated in the smaller section of the funnel (sections A and B in Fig. 72), until it reaches very high speeds (500-1400 m/min., depending on the flow and on the diameter). The liquor flow is powerfully directed towards the fabric inside the transport tube. The friction generated by the rapid liquor flow between the dye solution and the rope lets the fabric float through the tube; at the same time, the powerful motion of the flow facilitates the removal of creases on the rope.

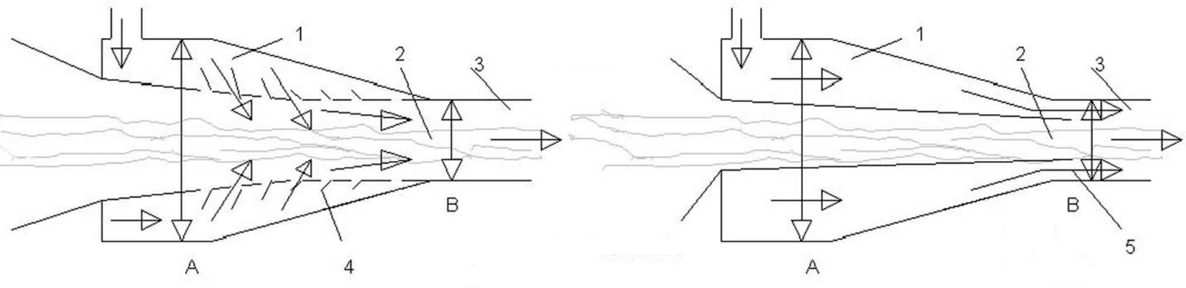


Fig. 72 Scheme of the ejectors

1 – Jet *4 – Keying*
2 – Fabric *5 – Neck*
3 - Transport tube

The circulation speed of the fabric can be adjusted as follows: in older machines, a by-pass provided with an adjustable valve controls the liquor flow to the nozzle and consequently the transport speed of the fabric; in more recent models, this adjustment can be carried out by means of variable flow pumps equipped with inverters and/or adjustable nozzles.
Generally the liquor must be recirculated at least every 30-60 seconds: at each recirculation, the liquor passes through the heat exchanger, thus performing an excellent control of the temperature also for fast heating or cooling; this allows a fast and uniform dyeing. The fabric rope must carry out a complete cycle every 1-2 min. (to avoid wrinkles due to excessive dwelling times inside the vessel).
The type of nozzle and its size also determine the weight range of the fabrics to be treated. Some machines are particularly suitable for light, medium- or heavy-weight fabrics, while others can process fabrics of different weights by replacing or adjusting the nozzle.
The operating conditions of this type of machine ensure a fast and uniform distribution of the dye (or of other chemicals) on the fabric and therefore short process times; the cloth is moved along the tube at very high speeds (up to 400-600 m/min), and short staple and delicate fabrics can be negatively affected by scratches or by the formation of hairiness on the surface. The great speed difference between the liquor and the fabric rope flowing inside the tube as well as the lifting of the fabric from the collection vat can cause possible distortions on stretch-sensitive fabrics.

Some machines of recent design are equipped with various clever devices, as large-size winches, wide winding angle of the fabric on the winch, adjustment of winch speed to fabric effective speed, minimal lifting height of the fabric out of the bath, mirror-finished internal surfaces. All these measures permit to handle at optimal conditions, i.e. in absence of tensions and without any risk of deformations, not only fabrics in man-made or artificial fibres, but also delicate fabrics in natural fibres. Moreover anti-twist systems, control devices of the lamellar bath flow both in the ejector and in the transport channel, as well as control devices on fabric folding, permit to prevent the twisting of the fabric rope and also fabric folds overfeeding when the fabric is being guided into the internal vats.

Other manufacturers, besides adopting some of previously mentioned devices, introduced a bath distribution system also in the upper part of the dyeing channel, obtaining optimum results in dyeing and also in the scouring, relaxing and decortication processes.

Completely filled jet machines: the shape can vary depending on the manufacturer's design; the access door is generally positioned in the upper part of the machine, near the nozzle, which is always immersed as well as the processed fabric. The transport principle of the rope is similar to the principle of outside nozzle jet systems, but in complete filling jet systems the flow directed on the rope in the Venturi tube (nozzle) is more delicate; this avoids excessive tensions, stretches during the lifting and frictions with metal parts. Also the peak speeds in fabric circulation are limited (200-230 m/min.) if compared to those of partially filled jet systems. As a result, it is possible to treat delicate fabrics, more subject to peeling or to the formation of hairiness on the surface.

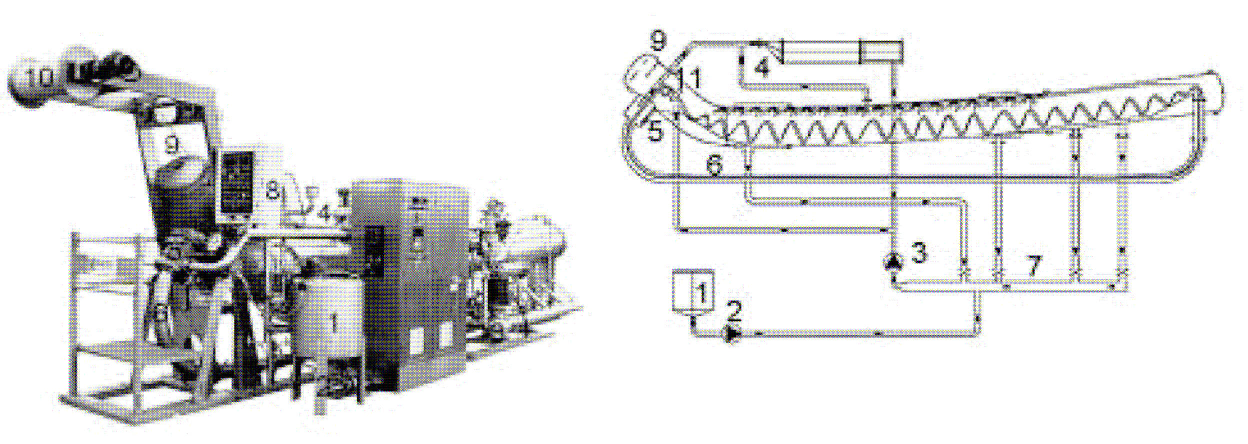
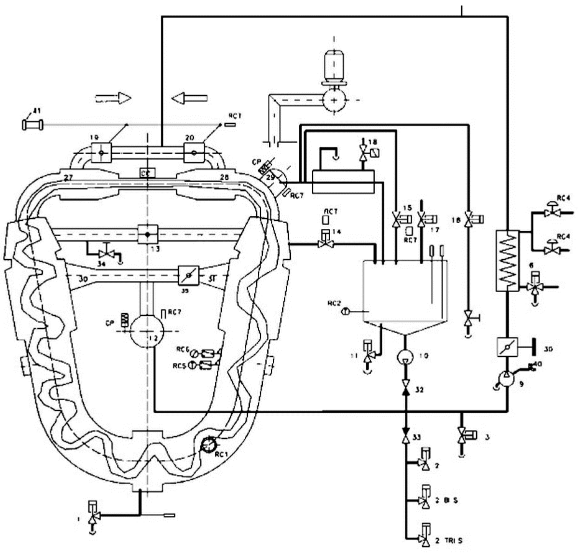


Fig. 73 Jet machine

1. Addition vat and filter
2. Addition pump
3. Circulation pump
4. Bath distribution device
5. Jet
6. Transport tube
7. Bath drawing system
8. PLC and control board
9. Loading door
10. Unloading winch
11. Winch and anti-twisting device

In reality, these machines have been working in mills for years, but they run with high liquor ratios (1:15-1:25) at high costs deriving from huge energy consumption (heating, maximum demand for pumps), from considerable water, chemicals and therefore effluent treatment costs, and finally from long processing times (lower number of cycles per minute).
Completely filled jet dyeing machines now available on the market have been designed to run with limited liquor ratios (1:10-1:12) which allow the processing of delicate fabrics in wool or fibre blends with short processing times and at low costs.
Fig. 72 shows a jet machine with total-filling, which can work with a liquor ratio of 1:12 and three cycles per minute; this provides a non-stop control of the temperature and ensures an excellent exchange between the liquor and the material. A special device including two jet systems has been designed to allow cloth motions in both directions, thus enhancing dye consistency and preventing rope entanglements.



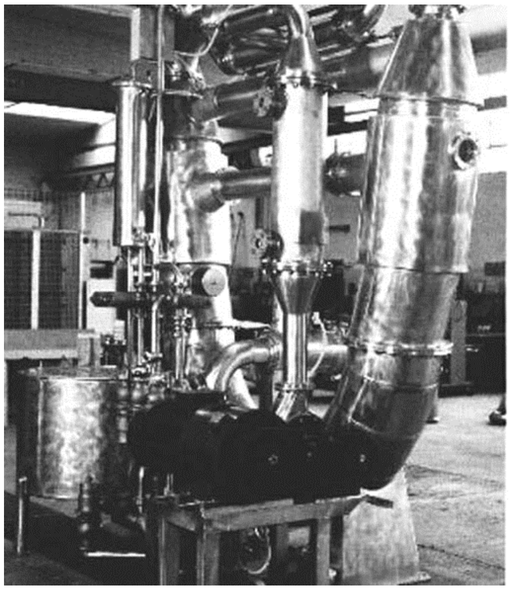


Fig. 74 Jet machine with total filling

Overflow machine

This dyeing machine is used for pre-treatment and dyeing of rope fabrics, with both liquor and materials moving; the architecture and the design of the system and the liquor ratios are similar to the jet machines.

The main difference is the fabric transport system, driven partly by a motorised reel, and partly by the sequential flow of the liquor. The jet system nozzle, based on a Venturi tube, is replaced by a vessel containing the liquor; the liquor enters the straight pipe section and then flows through the transport channel, together with the fabric rope. During this stage, the fabric is subjected to slight tensile stresses and to small friction forces, due to the progressive acceleration caused by the drop of the liquor, to the limited speed on one side and to high liquor flow and tothe large-size transport tube on the other. This machine is therefore suitable also for delicate fabrics, provided they are not wrinkle-sensitive.

The transport speed of the fabric is adjusted by the reel speed and by the water flow that the pump forces into the fabric transport tube (60-250 m/min.).

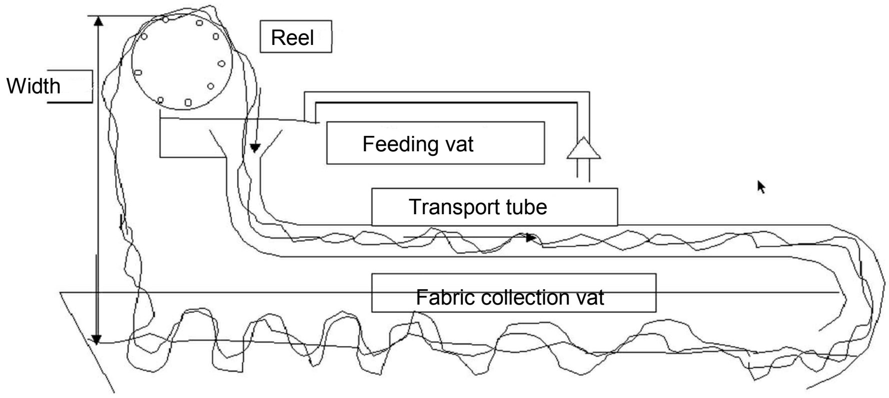


Fig. 75 Overflow machine

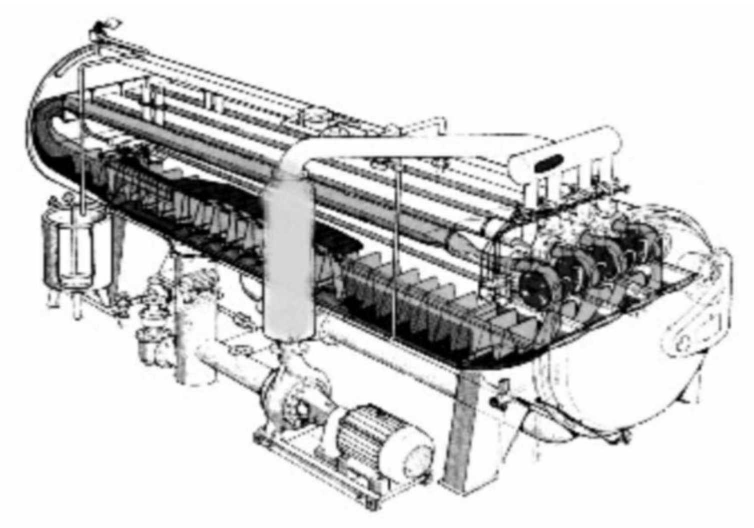


Fig. 76 Scheme of four-rope overflow machine

The manufacturers of overflow machines can supply machines working at high temperatures (from 130 to 140°C), particularly suitable for processing man-made fibres, artificial fibre and their blends, but also machines running at atmospheric pressure, particularly suitable for treating natural fibres (these machines generally reach operating temperatures from 98 to 108°C and are slightly pressurised to avoid cavitation effects in circulation pumps when working at temperatures near 100°C, see Fig. 76).
Now different types of jet and overflow systems are available on the market and manufacturers have designed special devices to make them even more versatile and suitable to meet the continuously changing customer needs.

Let us mention just some of the most interesting solutions:

- Flow-jet machines: to transport the fabric, these machines apply a system based on the Venturi principle, also known as fall-flow principle, and a motorised reel (Fig. 77B and D).
- Flow-jet machines with adjustable nozzle to allow a non-stop change of the transport effect (when the nozzle is closed, the jet effect is very powerful, whereas when the nozzle is open the machine runs in the overflow technique) (Figs. 77A, C and E, see scheme of variable nozzle in Fig. 77F).
- Vertical machines, where the fabric is lifted to 1-1.5 m. over liquor level, with low stress on the fabrics (these machines ensure high transport speeds and are suitable above all for continuous artificial and man-made fibres) (Figs. 77A, B, D and E).
- Horizontal machines, where the fabric is slightly lifted over liquor level, with low tensile stresses and transport speeds (machines suitable for delicate fabrics) (Fig. 77C).
- Machines with long (Figs. 77B and C) or short (Figs. 77A and D) transport tubes or with differently shaped tubes, to better suit the various requirements and the various types of fabric (Figs. 77A, B and D).

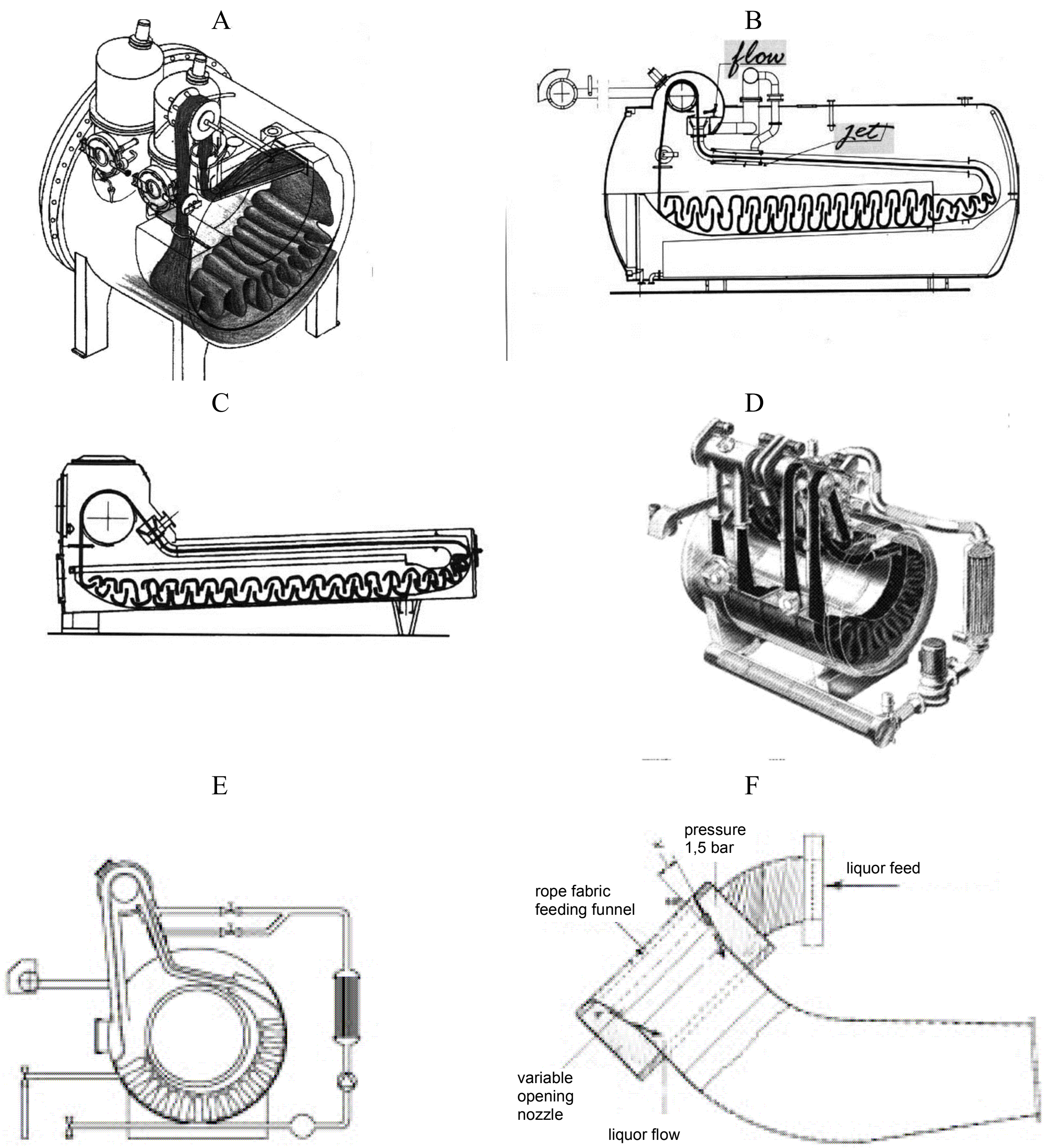


Fig. 77 Various types of jet and overflow machines, variable trim nozzle

- Machines with slant or Teflon-coated collecting vats, to improve the sliding of the folded fabric and reduce the problems of pulled fibres, abrasion spots and/or snarls (Fig. 77 C).
- Transport tubes slightly inclined upwards, to reduce the friction of the rope with metal surfaces (the fabric is drawn always immersed in the liquor) (Fig. 77C).
- Air blowing in the nozzle or in the flow, to favour the shifting of the rope folds.
- Air jets blowing under the reel, to reduce possible abrasions on the fabric.
- Separation of part of the rope liquor in the last part of the transport tube, to reduce the speed of the fabric when entering the collecting vat, thus avoiding irregular folding and entangling.
- Hydraulic systems, to improve a uniform folding of the fabric without entanglements .
- Possibility to drain the liquor at temperatures over 100°C (when possible, in order to reduce the process times) (Fig. 77D).

To optimise either output capacity or production flexibility, the machine manufacturers have studied different solutions. It should be taken into account that the loading capacity (in kgs) of the machine depends on the maximum liquor volume that can be used and on the liquor ratio; the weight of the fabric (as previously stated, the process time of one rope cycle must not exceed 2 minutes) can affect the maximum width of the rope and therefore the maximum load in kgs.
Briefly, to process lots of different sizes (from 50-60 kgs to 800-1200 kgs), the manufacturers can build machines capable of loading many ropes (with separate collection vats (Fig. 76 and Fig. 79), or machines with only one rope and variable path (Fig. 77 D), which last permits under the same load to reduce dyeing times.
To increase process flexibility, the machines (with 1, 2, 3 or more ropes) can be twin-type, namely two identical machines can work two different lots separately; if needed, the two machines can be linked and process simultaneously the same lot with the same liquor and at the same operating conditions, thus doubling the loading capacity (Fig. 78).

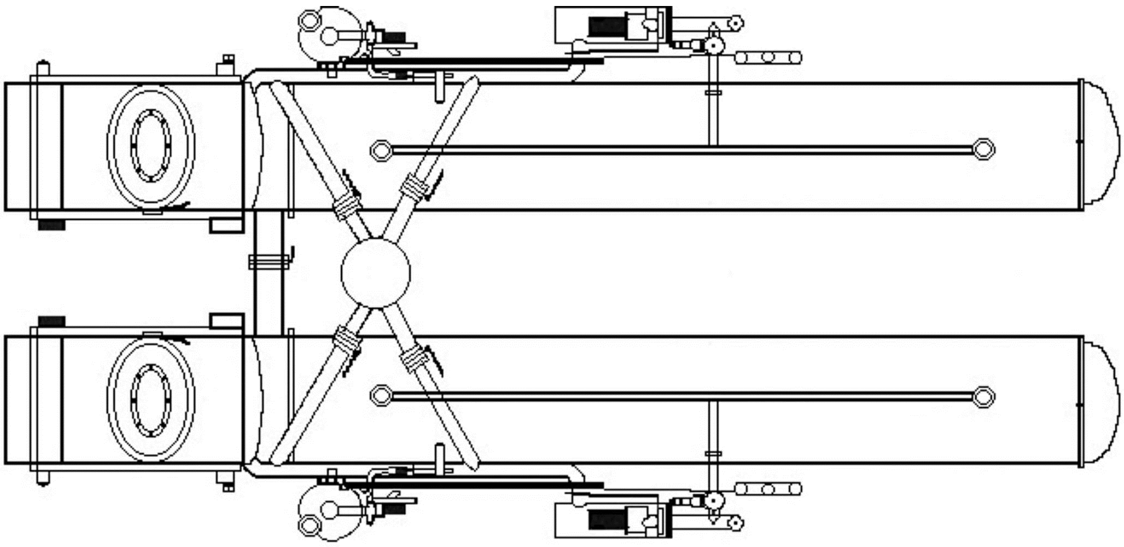


Fig. 78 Twin flow machine

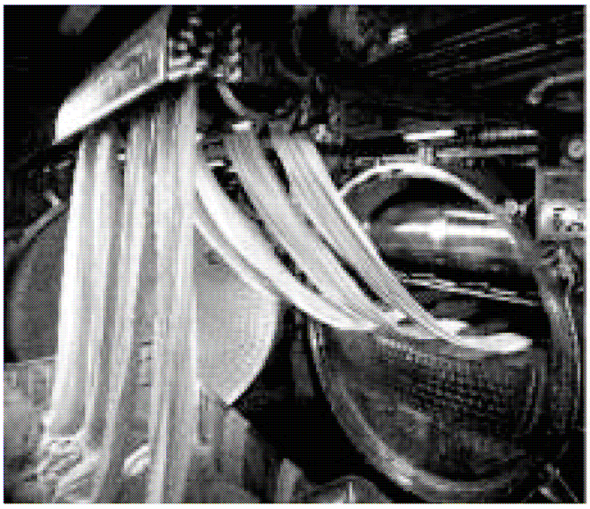


Fig. 79 Delivery of three-rope flow machine

Both jet and overflow machines are equipped with a motorized winch for loading and/or unloading the fabric (Fig. 79).

Air Jet machines

These are the latest rope dyeing machines launched by the manufacturers for fabric rope dyeing. The operating principle is similar to the jet dyeing system but the fabric, guided by a motorized reel, is exposed inside the nozzle to a stream of forced air, blowing from one or two turbines (or fans) which take the air from inside. During the transport stage or at the exit of the transport section or, if necessary, in both areas, the rope is sprayed with a controlled quantity of dyeing liquor; the atomised quantity of liquor slightly exceeds the absorption capacity of the fabric. When the fabric is folded into the perforated collection vat, it releases the excess liquor, which is recirculated by a pump.

The fabric transport speed can be also very high (between 250 and 1000 m/min), while the liquor ratio could be, in theory, 1:1 to 1:2; in standard processing conditions, the liquor ratio is 1:3-1:8. This machine usually allows high temperature processing.

The high speed of the fed fabric, together with the reduced liquor ratio, guarantees optimum dyeing results in very short times; it also reduces water consumption and the necessary quantities of auxiliaries and dyes, with consequent cost reduction (including waste water treatment costs). This applies particularly to dyeing, above all in the case of dyes with low affinity for fibres and low exhaustion percentages. However sometimes the low liquor ratio could cause problems due to the poor solubility of some dyes and/or during subsequent post-dyeing washing process, when higher liquor ratios would be more advantageous.

These machines were designed for dyeing fabrics in man-made fibres, blends of man-made and elastic fibres, and microfibres; in practice these machines have proved to be extremely suitable, in particular for dyeing fabrics in man-made filament yarns. While air feeding facilitates the continuous motion of the fabric and reduces possible defects due to rope folding, the fabric tends to pack on the bottom of the machine owing to the extremely reduced quantity of liquor, thus leading to setting of permanent folding wrinkles.

This problem becomes evident above all in the case of fabrics in man-made fibres, particularly when they have not been efficiently heat-set, and sometimes is amplified by the sheet of water conveyed onto the fabric at the exit of the nozzle.

These machines can process lots from 100 to 600-800 kgs, depending on the size of the machine and of the ropes.

Many solutions applied to jet and overflow systems are suitable also for air jet systems:

Teflon-coated vats, folding control, forced liquor drain, multi-tunnel (or multi-rope) machines. In detail, the machine shown in Fig. 80 is equipped with:

1- Winch, for feeding the fabric at variable speed ranging from 250 to 700 m/min. (1,000 m/min. with a pressurised machine).
2- Fan, for feeding the ejector by taking the air from inside.
3- Machine internal washing system.
4- Transport channel, facilitating the progressive rope opening.
5- Introduction of the atomised liquor at the exit of the channel (it reduces the impact of the fabric against the grid).
6- Adjustable contact grid.
7- Liquor spraying nozzle in the transport tube.
8 – Air blower at the centre of the machine (for improved soundproofing).
10- Teflon-coated collection basket of gradually larger section.
11- Fabric collection system with external control.

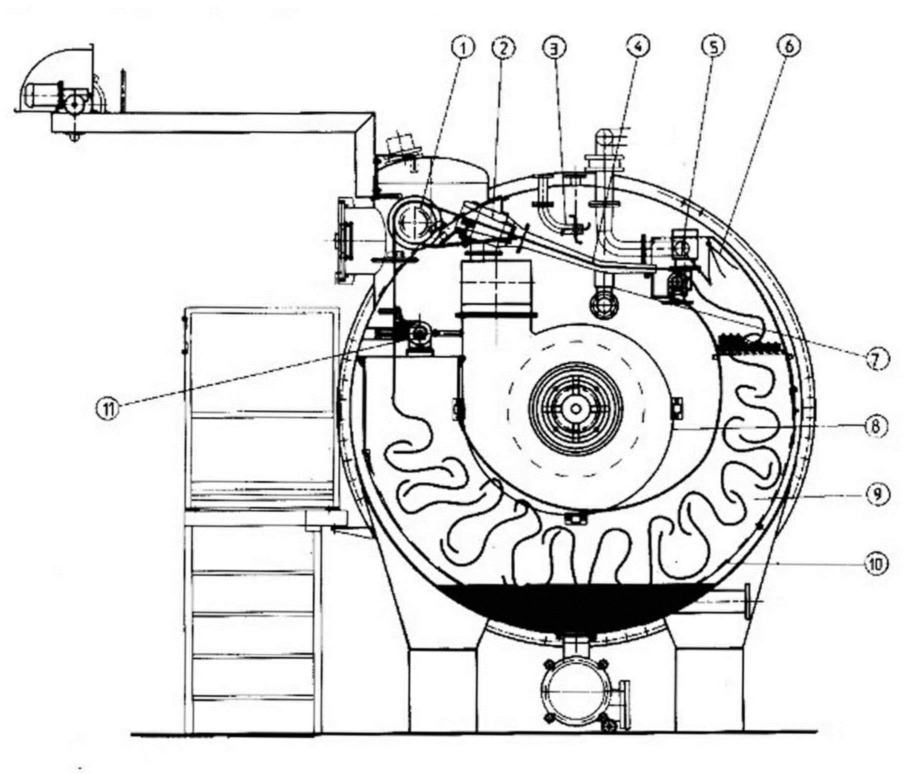


Fig . 80 Scheme of air jet dyeing machine

Fig 81 Rope path

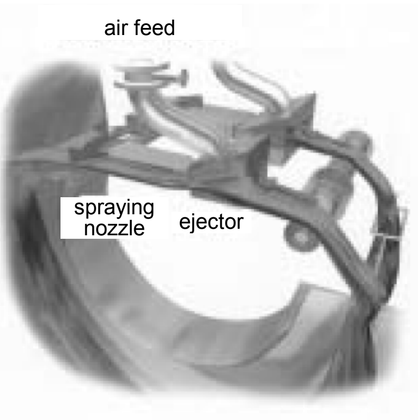


Fig. 82 Ejector detail

The application of electronics and IT systems allowed the introduction of devices specifically aimed at storing dyeing programs and continuously keeping all the operating conditions under strict control, displaying them on the control screen and eventually storing them in a central computer:

- Devices for detecting the passage of the magnet introduced in the sewing, with consequent calculation of the average rope circulation speed and possibility of stopping the sewing near the machine door for quick sampling.
- Electronically controlled pumps, reels and variable-speed air blowers.
- Devices for measuring the transport tension of the fabric and subsequent adjustment of the rope feeding speed (if the tension exceeds preset values, it slows down the reel and reduces the pump flow, to avoid possible deformations and abrasions).

- Setting, storage, control and recording of the dyeing cycle (temperatures, operating times, dyestuff additions, etc.), retrieval of additions from the automatic colour kitchen (or from the addition vat) and luminous and/or acoustic alarms for the operator.
- Security systems for door opening in pressurized machines.
- Possibility of recovering heat by pre-heating fresh water with the exhausted liquor.

Operations to be carried out during the process cycle:

- New planning of the process cycle or retrieval of the previously stored cycle
- The water (cold/preheated/softened/hard water) is introduced and its level is controlled.
- The fabric is conveyed into the machine unwound from a beam or folded on a carrier, by means of jet or flow system.
- The starting end of the fabric is recovered from the collection vat and the piece is sewn end-to-end.
- A magnet is introduced into the fabric sewing zone (in particular in case of machines working at high temperatures).
- The cycle is started.
- Possible addition of chemicals/dyes (automatically from colour kitchen, semiautomatically or manually from addition vats).
- The process variables are monitored on the control board; a visual control is carried out through the machine window.
- In dyeing processes, colour matching must be controlled at the end of the process cycle. The door is opened and a sample is taken near the top/bottom sewing (if necessary a correction cycle must be started).
- The fabric is, if necessary, washed and/or rinsed.
- Once the cycle has been terminated, the sewing is removed and the fabric is unloaded by means of a motorized reel.
- Machine washing.

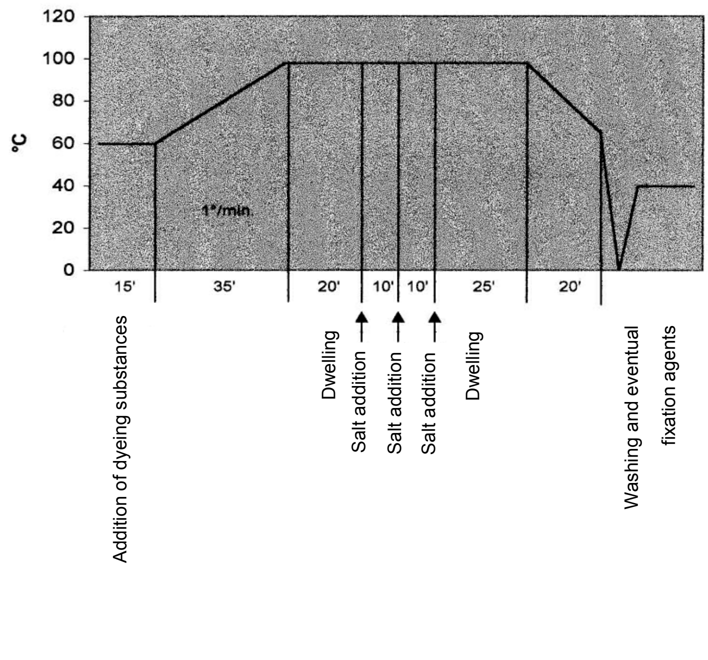


Fig. 83 Example of a dyeing diagram, as displayed on the monitor of a dyeing machine

Jiggers

These machines are in use since long time to treat medium-size lots of woven fabrics with an open-width exhaust dyeing process.
The fabric moves while the liquor stands still, except for the latest machines which are equipped with a circulation pump.

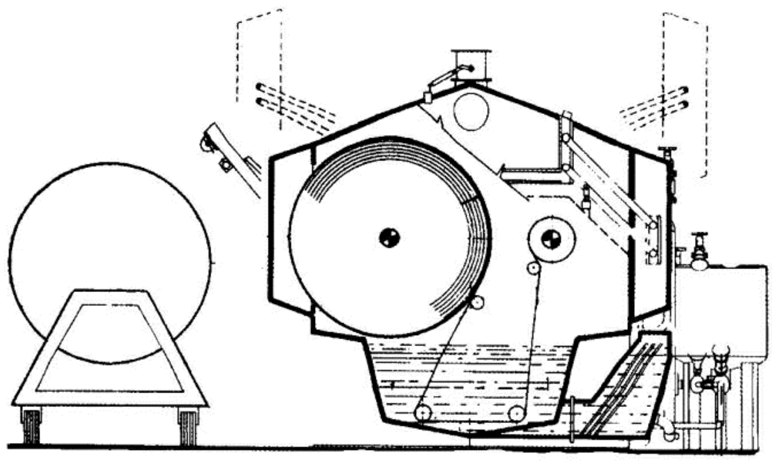


Fig. 84 Scheme of a jigger

The fabric pieces are sewn together end-to-end, to form a sort of long ribbon. At the starting end and at the final end of the ribbon, two cloths are added (4–5 m long) to allow the regular dyeing of the whole pieces, while leaving the machine drawn-in once the dyeing process has come to an end. The assembled pieces are unwound from a roll, pass through the liquor (they are kept in the correct position by means of guide cylinders and of a tension equalizer, which avoids the formation of wrinkles). The fabric is then wound on a take-up roll, until the dyeing process is ended.
The piece through-speed and tensions are adjusted by special devices to avoid any change in dimensional stability, above all when treating lightweight fabrics and/or delicate fibres. The maximum diameter of the roller can be 1,450 mm, with a piece width ranging between 1,400 and 3,600 mm. The piece through-speed is adjusted between 30 and 150 m/min. and kept constant during the whole operation. Also the tension must be constant and can be adjusted between 0 and 60 kg. Since the passage time is very short, dyeing occurs generally on the fabric wound on rolls.
The composition of the liquor absorbed must be as uniform as possible on the whole width and length of the fabric piece; for big lots, additions may be necessary to avoid the so-called end-to-end unevenness defects. Lightweight fabrics (viscose, nylon) that are excessively stretched during the take-up step, might show moireing defects. Jiggers work with a rather low liquor ratio (from 1:1 to 1:6).
Besides standard atmospheric systems, manufacturers also offer HT jiggers housed inside autoclaves, in order to operate under pressure.
Jiggers are used to dye every kind of fibre.

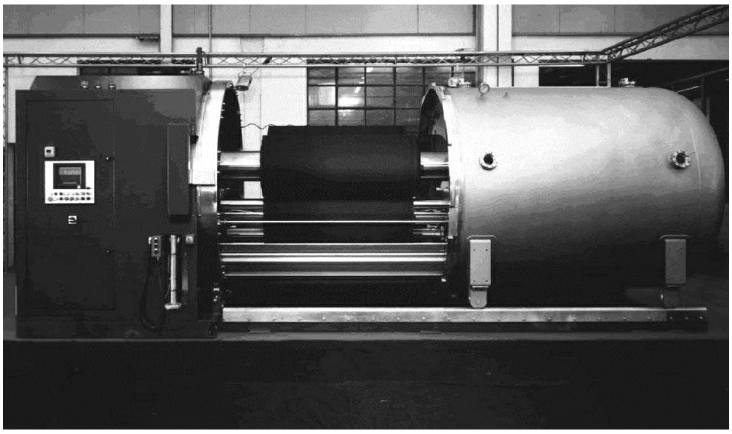
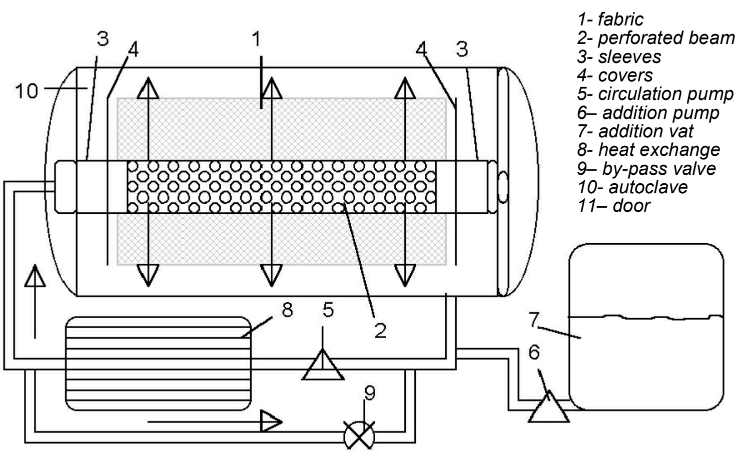


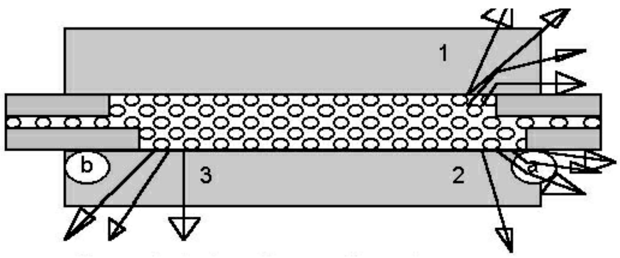
Fig. 85 HT jigger

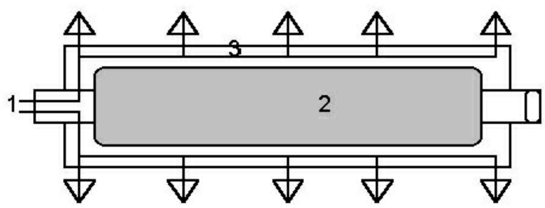
Beam dyeing machines

The discovery in the 1960s of polyester - a material which required very high dyeing temperatures (up to 140°C) - led to the extensive application of beam dyeing machines; these essentially include a dyeing autoclave with circulating liquor, with the open-width fabric lying on a perforated beam provided with plates.



Today, in order to increase the output capacity and further reduce the liquor ratio, manufacturers begin to provide their beam dyeing systems with large-diameter perforated beams, equipped with internal plenum chambers to reduce idle spaces.
Sleeves are used to equalise the liquor flow in the "selvedge" section





1 - correctly fitted sleeve
correct liquor flow
2 - loose sleeve
excessive liquor flow in (a)
3 - sleeve too tight
poor liquor flow in (b)

1- liquor circulation
2- plenum chamber
3- perforated beam

Fig 86 Scheme of a beam dyeing machine

The liquor, forced by a circulation pump, flows out through the holes and passes through the fabric, forcing the dye into the fabric. The liquor path can be reversed. If the fabric width is lower than beam width, the holes not covered with fabric are closed by means of covers fixed under the fabric.
The fabrics must be wound with the correct tension; if the fabric is excessively stretched, the liquor cannot pass and the dye is not forced into the fabric. On the contrary, if the fabric winding tension is not uniform, a moiré effect will originate. The control of pressure changes (internal to external), which must range between 0.1 and 0.5 kg/cm^2, allows the control of winding accuracy; several photocells monitor possible fabric unwinding.
This machine, which was very popular during the 1960s and the 1970s, is still widely used today and is even experiencing a sort of revival. The liquor ratio varies between 1:10 and 1:15, but the use of internal plenum chambers allows the optimisation of the required liquor volumes.
The machine can be used for both preparation and dyeing operations.

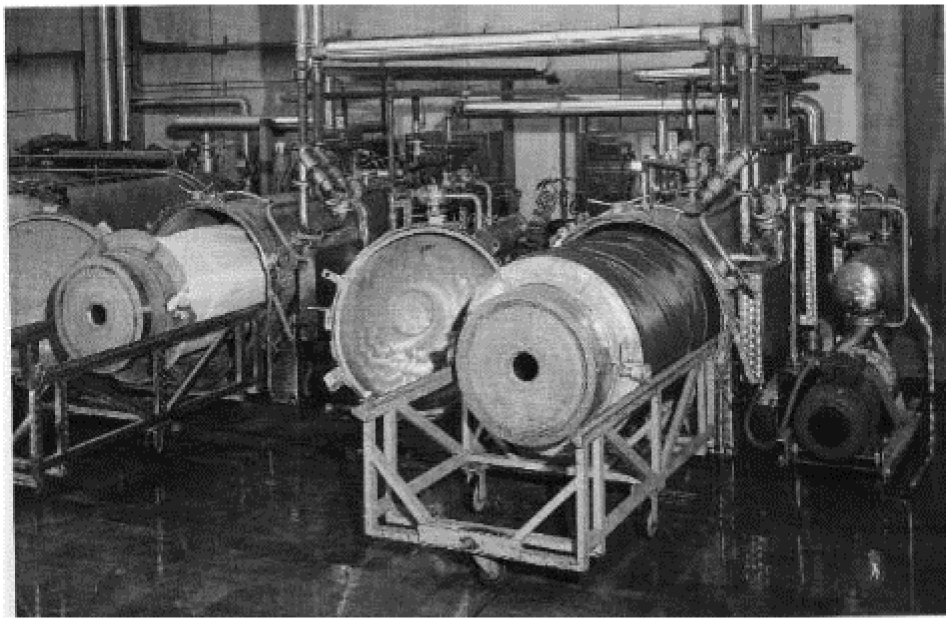


Fig. 87 Beam dyeing machine

Fot the dyeing of fabrics wound on cylindric elements (beams) and for the dyeing of yarns on cones or of warp beams (autoclave), a particular process has been developed, which bears the names HPF (High Pressure Flow) and HPF-HS (HPF+High Stop).
This process permits to dye also very densely sett fabrics or yarns wound on high density cones, microfibres, low-twisted filament yarns while operating with higher machine loads than usually admissible for that type of product, without distorting the goods and without preferential flowing lines, thus avoiding all defects connected with these problems. This ensures a reduction of processing time and of production costs, or (with same labour time), better results in terms of evenness inside to outside, even without reversing the direction of bath circulation.
The HPF and HPF-HS process ensures maximum advantages if used at the same time with the integrated system SCR 3000 PV for the automatic control of the fluid-dynamic parameters.

Garmentdyeing machines

During last decade, the market forced the textile companies to supply sports- and leisurewear with extremely reduced delivery times and in the trendiest colours of the moment. As a matter of fact, the standard textile production cycle, which needs a long sequence of operations before marketing its end-products (dyeing process followed by make-up and distribution), is not in a position to

assure such short delivery terms and could therefore not suit the market requirements of these particular fashion-oriented garments.
The garment dyeing process offered the solution with very short delivery times from customers' request to the fulfilment of market needs, in terms of fashion colours and/or of finishing treatments. At present there are several manufacturers offering various machines specifically designed for the dyeing and finishing of ready-to-wear garments. These are generally rotating machines, similar to big industrial washing machines; the garments are loaded in special baskets for finishing operations. The machine size and the equipment allow to meet the most different needs as described in the following.

1- Sizes: from sampling machines with a 50 cm basket and a capacity of 90-110 litres to dye and finish small lots of garments, to manufacturing machines with 2.8 m basket and capacities ranging from 8,000 to 8,500 litres, but with similar liquor ratios (to facilitate reproducibility).
2- Baskets: with different shapes depending on the type of materials to be dyed and finished (jeans, linen garments, knitwear, etc.) and on the different effects (ageing, delavé, enzymatic treatments for cotton, linen or Tencel).

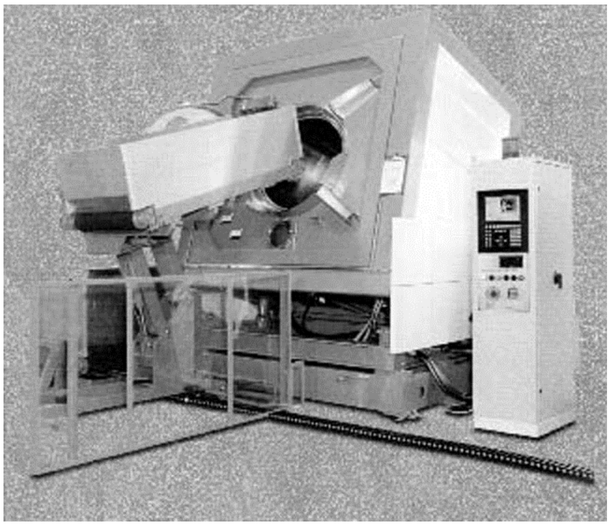


Fig. 88 Garment dyeing machine with PLC and robotized shuttle loading

3- Perforated steel sheet metals and beater covers to avoid damage to the basket when treating the fabrics with pumice (stone-wash, ageing).
4- Delta or star-shaped separators for treating very delicate garments.
5- Automatic systems for metering and dissolving dyes and auxiliaries.
6- PLC to program, store and monitor the treatment cycles.
7- Loading and unloading systems provided with robotized shuttles or tilting devices.
8- Automatic pumice separation devices during the unloading stage.

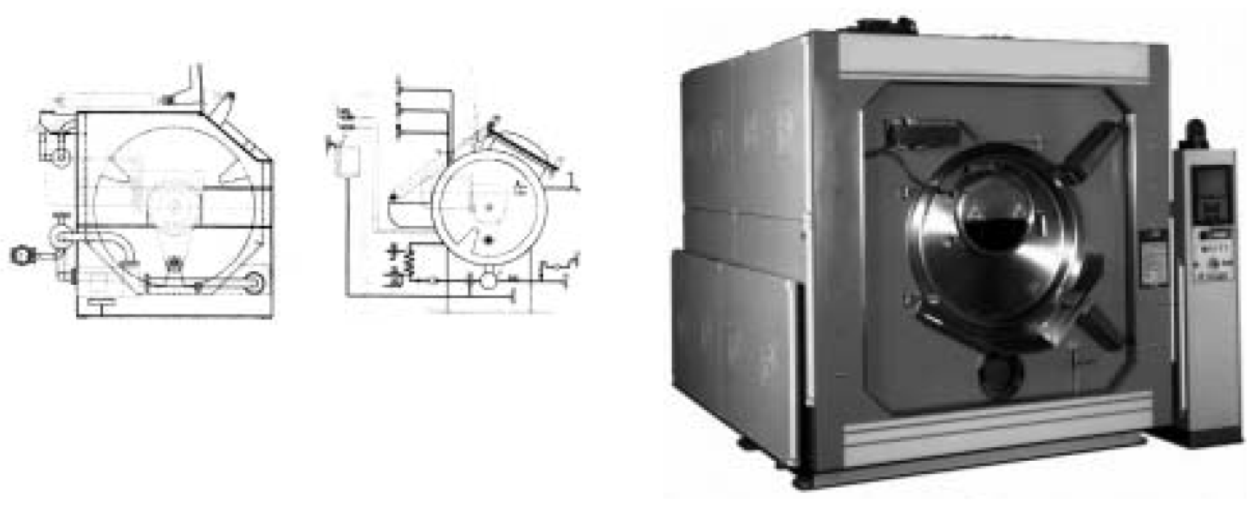


Fig. 89 Scheme of garment dyeing machine

The latest machines are „open basket” high speed machines. These machines allow to carry out a dyeing process during which the garments position themselves, as a result of centrifugal force, on the periphery of the basket and consequently are not subjected to continuous rubbing (on the contrary to traditional machines) and therefore do not experience any wear effect. Moreover the open basket permits to perform on the same machine both pre-dyeing and dyeing operations. The high turning speed of the basket permits the bath to pass several times through the material, wich means a quicker bath exhaustion and a reduction in dyeing time.

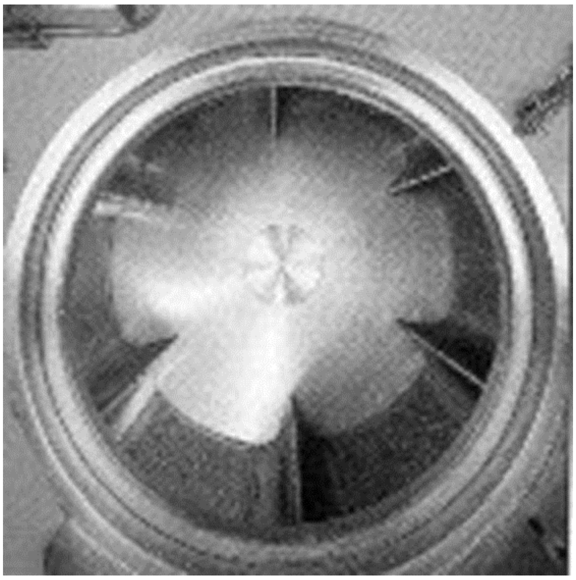


Fig. 90 Basket detail

Fig. 91 Pumice separator

It should be noted, that most machines can even work at high temperatures, thus allowing the dyeing of PE or PE-blended garments.

Dye kitchens

Dye kitchens were originally manual systems and all operations, namely weighing (of dyestuffs and auxiliaries) and dyebath preparation (dyestuff dissolving), were carried out by the operators of the dye kitchen.

However, this created several problems, both in terms of result reproducibility (matching and consistency of the dye, weight, dissolving procedure) and of operator’s safety and health.

The first development, concerning the second problem, was the use of special hoods (protective coverings, usually providing special ventilation to evacuate noxious vapours, dusts, and gases) introduced by manufacturers of granule or liquid dyestuffs. Wrong results due to human mistakes (or even to the actions of different operators) have been then corrected by introducing automated colour kitchens equipped with dispenser systems which can reproduce the recipes established by the operator by means of a computer-controlled system which weights, mixes and dissolves the dyes and auxiliaries.

The second development instead concerned the production of semi-automated dye kitchens, which retrieve the recipe to be reproduced, move the dye bins automatically and send the operator the required mix.

Another step forward has been brought about by automated colour kitchens: the dyestuffs are stored inside special containers and the operator, using a keyboard and a computer, retrieves the recipe to be sent to the production process. A container on a special weighing device moves every time under the screw conveyor, distributing the powders of the various dyes taken from the relevant container;

this process is controlled by a PLC. Once the weighing operation has finished, the necessary quantity of water is added at the temperature established by the dissolving procedure, the dyes are dissolved by agitation and the solution is sent to a special stand-by vat, before being poured into the dyeing machine. The container where the dissolving process is carried out is washed and dried automatically for the next cycle.

Pad dyeing machines

This dyeing process can be applied on open-width pieces, on fabrics that are particularly sensitive to creases and crush marks. Pad dyeing differentiates from exhaust dyeing in the dyebath application and fixation processes. Very reduced water quantities are required, resulting in lower energy consumption.

For dye application, the fabric is conveyed to spreading and stretching units which prevent the formation of creases, then into becks containing the dyebath and finally to heavy rollers which squeeze out the excess liquor. The fabric feeding speed must be constant.

It is important to add to the dyebath an impregnating agent allowing the efficient impregnation of the fabric in a short time; the dyestuffs used must also have the least possible affinity for the fibres, to avoid end-to-end unevenness. Pad dyeing dyestuffs must also be very soluble to avoid dotting defects due to precipitation when dyes are used in high concentrations.

It is necessary to use highest possible temperature, to facilitate the penetration of the liquor into the fabric (this is particularly important for very dense fabrics) according to the affinity for dyes of the fabric and to the stability of the dyebath.

The impregnation vat must be so shaped as to allow the fabric an adequate contact time for absorbing the dyebath, even with a reduced capacity of the vat and a high advance speed of the fabric; the reduced liquor volume facilitates a fast exchange of the liquor itself in the impregnation vat, thus reducing possible end-to-end unevenness defects due to the dye/fibre affinity.

The liquor absorbed by the fabric is constantly replaced in the impregnation vat thanks to a special tank and a distribution pump; this ensures the maintenance of a constant level of the liquor in the vat, while providing a uniform impregnation.

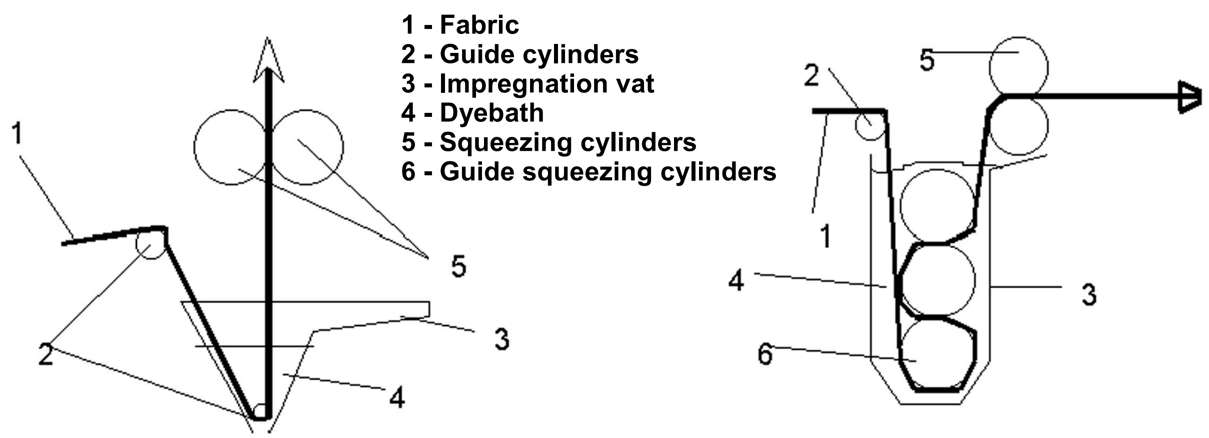


Fig. 92 Schemes of pad dyeing

The squeezing drums generally have a more or less flexible rubber coating wound on a stiff core (made of steel). High operating speeds, the use of aggressive products (for example, finishing process with or in presence of organic solvents), high pressures and temperatures require that the elastic material used for coating the rollers ensures high resistance levels that cannot be granted by one material only.

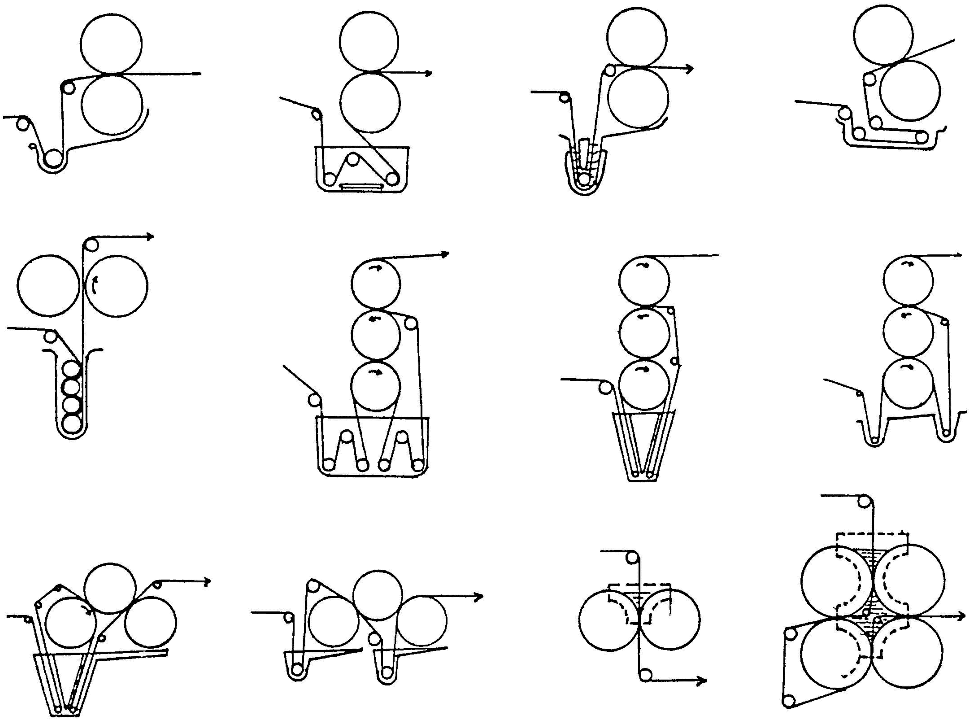


Fig. 93 Different types of pad dyeing machines

It is therefore necessary to choose the material more suitable to the different operating conditions.
For this reason, a wider range of materials is now used: natural rubber, more or less cured, and various types of synthetic resins, whose excellent elasticity is due to the curled shape (or spiral shape) of their macromolecules and to their mechanical and chemical resistance to the intermolecular cross-linking obtained, which complies with its elasticity (elastomers). The quantity of monomers from which elastomers are obtained is very limited (a dozen)) and the characteristics of the materials used for the coating are obtained by aggregating particular chemical groups to these basic components. During the dyeing process, the elastic material, which makes up the pad dyeing rollers, is constantly subjected to contact with aqueous solutions (sometimes alkali or acid solutions), with emulsions of solvents or with organic solvents.
It is therefore necessary to know the resistance of the materials used for coating the cylinders to the chemicals to be applied.
An important factor, which must be carefully taken into account during the pad dyeing process, is the pressure exerted on the cylinders, which is applied on the pins at the roller sides. The bending moment, acting on the cylinder and on its stiff core, produces a stress on its centre: the greater the bending, the longer the cylinder and the smaller its diameter.
Therefore the core of the fabric will be less powerfully squeezed; this problem can be avoided by means of a swollen cylinder, i.e. of a cylinder whose diameter in its central area is larger than at its edges. The central bending of the cylinders can also be reduced by increasing their diameter: when the diameter of a cylinder exceeds its length by 1/4, the bending is almost insignificant (an increase of the diameter increases the cylinder contact area and therefore reduces the pressure per square inch).

The pressure changes the shape of the squeezing cylinders in the contact point, thus generating a contact area, or "NIP" area.
In the nip area, the pressure reaches the highest value in the central area. The result is a function with the typical parabolic curve shown in the figure. The nip area formed by two elastic cylinders is wider (cylinders have the same diameter and pressure) than the one formed by stiff cylinders. Therefore the pressure per square inch will be lower, but the area where the pressure is applied will be wider and consequently the squeezing time will be longer.
By using the new-concept cylinders (for example the "ROBERTO" cylinder), the removal of water on the surface and subsurface water is carried out more completely than with traditional cylinders with flat surface.
The elastic coating of such cylinders is made up of a thick layer of fibres, individually coated with a thin sheet of rubber. The result is a porous material allowing the easy draining of the solution from the compression area with an alternate action of compression and expansion of the pores of the elastic coating.

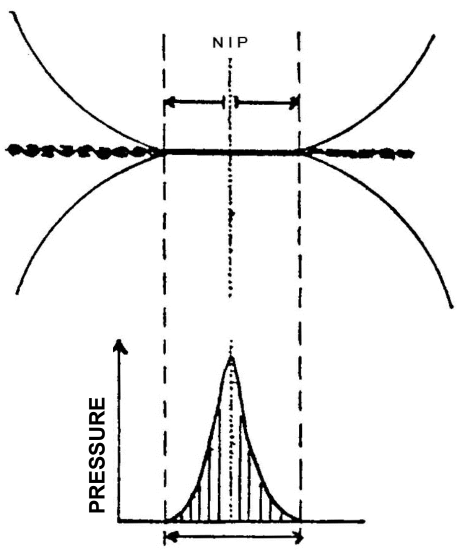


Fig. 94 Nip area between the squeezing cylinders.

This cylinder works against a cylinder in "hard" metal or hard rubber. In standard dyeing pads equipped with smooth cylinders, the maximum squeezing effect is reached at the centre of the nip area, where the pressure is at its maximum level: in order to leave the fabric, water must however overcome the resistance to slipping of the fabric which is compressed in the nip area. By using these porous cylinders, water is compressed in the porous coating of the cylinder and can be easily removed from the fabric.
Furthermore, once gone beyond the centre of the nip area, the pressure decreases and the expansion of the "pores" of the elastic coating determines a vacuum effect, which produces the aspiration of residual water.
The elastic coating of the cylinders is less subjected to permanent deformations: selvedge marks, signs of knots, wrinkles in the material, etc. are levelled after some revolutions.
Evident damages may require a grinding treatment.

Fig. 95 Removal of water from the fabrics by means of cylinders with smooth and porous surface (the arrows show the water flow direction)

An ideal condition for pad dyeing is that neither the substances dissolved (or dispersed) nor the solvent have any affinity for the material to be processed. Bearing this principle in mind, the quantity of the solute deposited on the material depends only on the liquor concentration and on the squeezing degree. Since the composition of the liquor left on the fabric is the same as the one inside the pad vessel, it can be restored during the application process by adding a solution with the same composition. When solutions of dyes or finishing products have some affinity for the fibre, a better absorption of the solute is achieved while, with other products (for example finishes), a better absorption of the solvent is achieved. As for the application of dyestuffs also during the finishing

process, this better absorption is expressed by "D.P.F." (Dye Pick-up Factor) which is the ratio between the quantity of compound successfully deposited on the fabric and the quantity that should be deposited, according to the concentration of the liquor and to the squeezing ratio (expressed in per cent value). As the pad dyeing speed increases, the D.P.F. gets closer to 100, since the material remains for a shorter time in contact with the dissolved substances. The concentration of the finishing products in the storage container feeding the dyeing pad vat will compensate the concentration variations of these products in the impregnation vat, if they have a D.P.F. significantly different from 100.
Another factor to be taken into account is the so-called pick-up or squeezing degree which represents the quantity (expressed by the weight) of liquor dispersed in 100 kg of fabric, after impregnation and pad squeezing; the lower the value, the better the squeezing effect. A high squeezing level is generally preferred since it reduces the quantity of liquor dispersed between one thread and the next one, enhances the penetration of finishing products, allows significant energy savings during the drying process and reduces the migration phenomenon during drying. The poor mechanical resistance of the fabric or the limited solubility of the finishing products could suggest high pick-up values. The pick-up depends, besides on the characteristics and on the fibre composition of the fabric, also on following parameters:

- pressure exerted by the cylinders;
- hardness of the roller coating;
- liquor viscosity;
- roller size;
- operating speed;
- fabric preparation;
- presence of auxiliaries.

Once the treatment has come to an end, it is necessary to eliminate the pressure immediately and "release" the cylinders, to avoid the formation of foulings and deposits.
Also necessary:

- to avoid working with saturated or almost saturated solutions, which could deposit crystals on cylinders by evaporation of the solvent;
- to protect the cylinders from light, ozone, chlorine vapours and from the heat (radiant heat from heat-generating media, hot air convection, etc.), above all at the end of the treatments;
- to pay attention to the aggressiveness of solvents and chemical reactants used;
- to store the cylinders horizontally on their pins.

After the application of the dyebath on a pad dyeing machine, the dye is ultimately fixed on the fibre. For this purpose, we can indicate semi-continuous and continuous processes. More precisely:

- pad-batch process;
- pad-roll process;
- pad-jig process;
- pad-steam process;
- pad-dry process.

Semi-continuous processes

In *pad-batch* processes, a cold padding is carried out using auxiliaries and dyestuffs. The fabric is then wound up in rolls and covered with a plastic sheet to prevent the drying and oxidation of the outer layers. It is then rotated slowly for 8 to 24 hours to avoid percolation due to the gravitational effect of the liquid, which could distort the roll and create dyeing defects. The fabric is finally washed with auxiliaries (continuous or discontinuous systems).

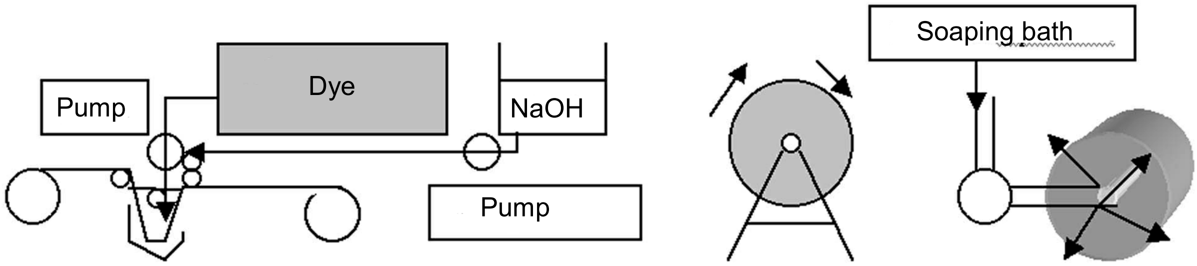


Fig. 96 Scheme of a pad-batch line

With the *pad-roll* process the fabric, after being soaked and heated with steam or infrared rays to obtain an even dye application, is kept in hot steaming chambers at 60-80° C for 2 to 8 hours, depending on the dye used and on the desired colour strength.
The *pad-jig process* is used for direct and reduction dyes. After pad impregnation, the fabric is wound on rollers and then passed through the jigger for the fixation treatment. In the jigger bath, 5-10% of the padding bath is added, to oppose any dye bleeding.
The fabric is then washed and rinsed.

Continuous processes

The *pad-steam* process is carried out by first impregnating and subsequently pad-squeezing the fabric; after that, the wet or pre-dried fabric is fed into a special steaming machine for fixing the dye. The steaming time depends on the temperature and on the dyes used.

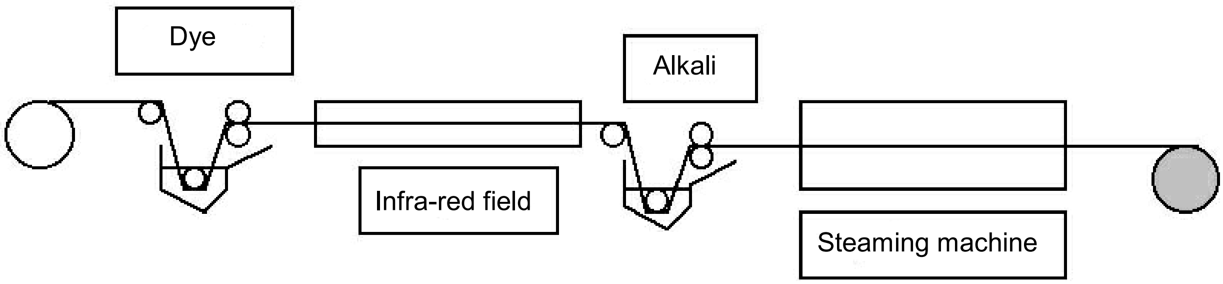


Fig. 97 Scheme of a pad-steam process

In the *pad-dry process,* after impregnation and squeezing the fabric is directly dried or pre-dried with infrared rays and fed into a hot flue to fix the dye. Finally the fabric is washed and rinsed with a continuous system.

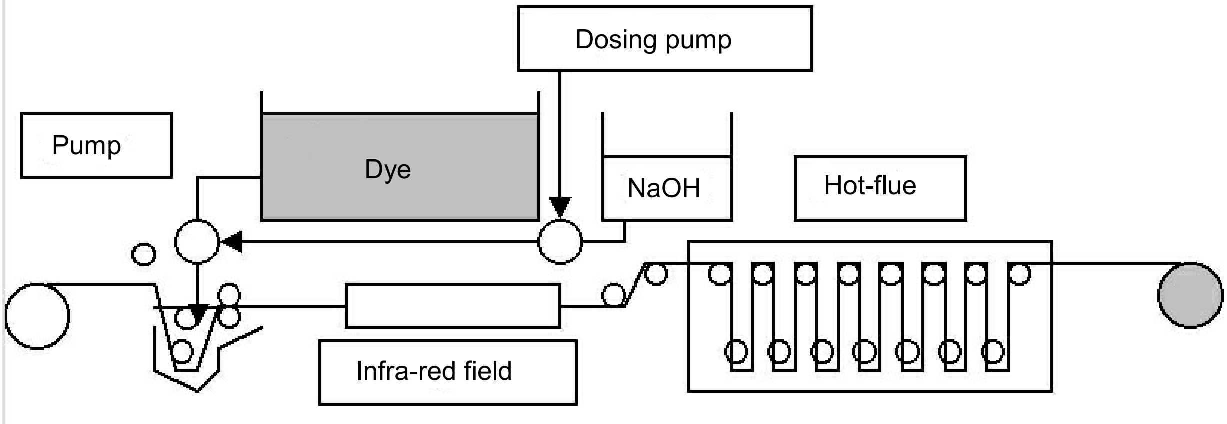


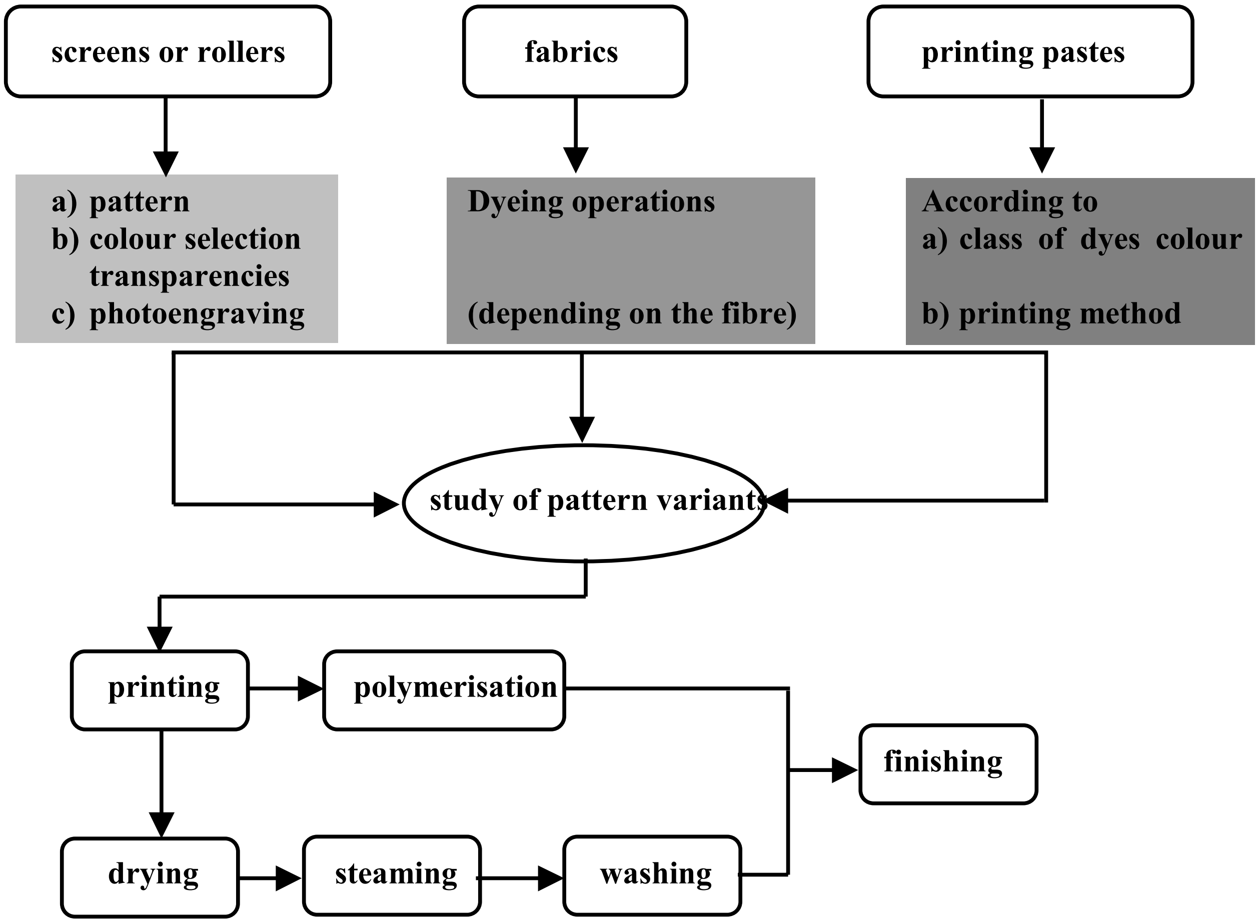
Fig. 98 Scheme of a pad-dry process

The three schemes above refer to dyeing processes of cellulosic fibres with reactive dyes.

PRINTING

Printing could be referred to as a sort of selective dyeing that makes an important contribution to fabric decoration thanks, to the combination of colours and dyeing methods.
To obtain sharply defined, precise and reproducible patterns, the dyebaths traditionally used are not sufficient, because of the capillarity and/or hygroscopicity of fibres and of the migration of dyes, that cannot grant sharp and well-defined colour patterns.
It is therefore necessary to use special liquids, conventionally called "printing pastes", whose main characteristic is a high degree of viscosity (improperly called density); in other words, these printing pastes are fluids which oppose a high resistance or friction to sliding or motion.
As a consequence, the dyestuff applied on the fabric in well-defined areas to reproduce the desired pattern cannot migrate to other areas of the fabric. It is also worth considering that the high viscosity of printing pastes will make the dye adhere to the surface of the fabric and of the fibres, but not penetrate into it and and get fixed. These operations (which may be referred to as diffusion and fixation during the dyeing process) will be carried out successively with a steaming process.
The application of the printing paste on the fabric is carried out by forcing it through the grey fabric on special printing blocks or perforated hollow rollers applied onto the fabric; the dye is then generally fixed by means of a steaming process.

Let us briefly outline the main operations necessary to obtain a printed and finished fabric:



Printing methods

There are different types of prints depending on the printing method, on the desired pattern and on the results to be obtained. Another approach to the printing classification can depend on the process and therefore on the machine used (manual screen printing, carriage screen printing, mechanized screen printing, hollow roller printing).

Direct printing

This method involves the following steps: printing, drying, steaming and washing.
This type of printing is generally used for white or dyed cloths (usually in pastel shades), by applying in sequence all the colours, until the original pattern has been reproduced.
This is the most common printing method and can be used with all the main colour classes of dyes and on fabrics produced with any kind of fibre (some problems may only arise with some blends).
The technical limits of this printing method appear with endless patterns (particularly with those obtained with screen printing methods, whereas no problem occurs with roller printing). Some problems may also arise when printing is made on grounds dyed with pastel shades: in fact, this could create problems on the areas of the design to be printed in light shades and limit the number of reproducible pattern variants.

Pigment printing represents an alternative to direct printing

With pigment printing there is no need to carry out a steaming process, as steaming is replaced by polymerisation (generally carried out simultaneously with drying). This type of printing process is very simple and cost-effective and can be carried out easily on all types of fabrics, particularly on blends, since pigments can adhere to all fibres; there is no need to use dyes of different colour classes. On the other hand the adhesives, which bind the pigments to the fabric, can give serious problems in terms of handle variation. For prints with low coverage ratio, the hand variation can be acceptable, but is not acceptable when the coverage ratio is high, or is at least not acceptable for all uses. Furthermore, the pigment lies on the surface and has low rubbing fastness (this depends mainly on the type and quantity of binding agent and on the polymerisation degree). Some valid alternatives to this type of printing can give special effects; such is the case of *printing with swelling agents* (generally synthetic polyurethane-based pastes are used), with covering pigments and with glitter (metal powders or particles of plastic materials), etc.

Four-colour printing

In the four-colour printing process, primary colours (magenta, yellow and cyan) plus black are used. The different shades are obtained by applying dots of the primary colours in variable densities: this technique also takes advantage of the ability of the eye to combine colours when observing them from a certain distance. Design patterns with different hues and tones can be obtained by using only four printing screens. This method however limits significantly the possibility of pattern varying. This technique is used only for fixed patterns, but pure saturated colours cannot be reproduced.

Discharge printing

Basic steps are printing, drying, steaming and washing. This technique is applied on dyed fabrics (usually in dark shades).

The fabric is dyed in the piece and then printed with a chemical that destroys the colour in designed areas. Sometimes the base colour is removed and another colour is printed in its place; but usually a white area is desirable to brighten the overall design.
This printing method is generally used to obtain designs with tiny details, sharp and well-defined edges on coloured grounds, patterns with low coverage ratio on coloured grounds, and to avoid pattern contact problems on endless patterns with coloured printing grounds. The results obtained with this printing method could be hardly reproducible with direct printing, since it would be very difficult to obtain wide grounds, smooth and well penetrated, with sharp edges without seam defects.
A problem for this printing method is the need to choose perfectly destroyable dyes for the printing grounds as well as dyes perfectly fast to the discharging agent for use as illuminants. The selection restricts the number of applicable dyes and in particular, for some dye classes, very few dyes grant a good fastness to light and moisture, although the colour effects are excellent. With this type of printing carried out on black or navy blue grounds, it is also impossible to check if the various colours are correctly positioned; any mistake will be visible only after the steaming process and at that point it would be impossible to correct it. This problem could be limited by testing the printing result on a white cloth at the beginning of the printing process.

Resist printing

With the old method of physical resist printing, hydrophobic products or printing pastes were applied to the fabric to avoid the physical contact with the subsequent dyeing liquor ("Batik" process)).
Now the most diffused printing system is the chemical resist printing, which is carried out with different printing methods, using pastes containing chemicals which avoid the fixation of ground dyes (particularly for "reactive on reactive" printing of fabrics in cellulosic fibres). Some of the printing methods are detailed in the following:

a) Resist printing on unfixed dyed ground: a pad dye is applied and dried; the printing is carried out with printing pastes containing products which prevent the fixing of the ground colours (but not the fixing of any illuminant used). The fabric is then dried, steamed and washed (this is the most diffused resist printing method).
b) Resist printing by overdyeing: the operations of the resist printing method previously detailed are carried out in inverse sequence; therefore the fabric is first printed and then pad-dyed with unfixed dye.
c) Resist printing by overprinting: this method is similar to the previous one, but the pad-dyeing with unfixed dye is replaced by the roller printing of the ground.
d) Printing on polyester: polyester printing must be carried out applying the resist-discharge printing method with pastes containing both the discharge and resist products applied on unfixed dyed grounds.

Transfer printing

This printing method is used for printing on man-made fibres, particularly PES.With this efficient method, disperse dyes, previously printed on special continuous paper, are transferred onto the fabric by means of rollers with engraved frames. The design is transferred by contact between the paper and the fabric, which is then passed through heated rollers at a temperature of 190-210°C. With this method, disperse dyes sublime (i.e. change directly from the solid to the gaseous state without passing through the liquid phase), penetrate into the fibres, harden and are fixed in a fraction of a second.
Recently some manufacturers are using this printing method also with acid dyes on PA and with reactive dyes on cellulosic fibres.

Devoré printing

This method is generally used for PES/cellulosic blends (more rarely for PA/viscose, silk/viscose, wool/viscose blends) specifically pretreated with acid pastes (potassium acid sulphate, chloride or aluminium sulphate); during the drying at 140-170°C, cellulose fibres carbonise, while man-made fibres (or protein fibres) remain unaffected by the carbonising process. A subsequent mechanical treatment (brushing or beating) followed by washing creates transparent pattern effects resembling laces; these fabrics are generally used for upholstery, underwear and garments production. Devoré printing can also be carried out on polyamide/silk or polyamide/wool blends, using strong basic discharge pastes to destroy the protein areas of the fabric. Today manufacturers frequently combine devoré printing with direct or resist printing, to obtain fabrics with extremely interesting effects. It is however necessary that the fabrics are thoroughly evaluated before applying this printing method, as the quantity of fibres to be removed must make up for at least 50-60% of the whole fibre contents in the fabric to get well visible effects, while the remaining fibres must be equally present in warp and weft, with a weave structure which permits sufficient stability on devoré-printed areas.

There are also many other types of printing, which are a cross between a real printing and a finishing operation:

Flocking: Flocking consists of printing the fabric with adhesive products, letting a fibrous material of 2-10 mm length named “flock” fall on the fabric through a sifter in order to be distributed uniformly, and then pass through a magnetic field which orientates the fibre material in vertical position. The fibres are then fixed by means of subsequent drying and polymerisation of the adhesive; finally, unfixed fibres are removed.

Metal foil printing: after printing the thermoadhesive product, the fabric is covered with a film made of polyester on which a thin metal coloured layer or a thin metal foil has been deposited by sublimation. The adhesive is then polymerised at 150-170°C; after cooling down, the film still sticked on the fabric is removed, so that patterns will originate in the zones of the fabric where the adhesive was applied.

Preparation of printing pastes

The preparation of printing pastes greatly differs from the preparation of dyebaths: during the dyeing process the liquor is prepared directly when used, while printing needs a different approach passing through the preparation of "master batches" and “cutting" pastes.
Master batches are printing pastes containing a high percentage of dye and all the necessary auxiliaries (except for specific cases where the auxiliary could alter the dye or the paste stability). Usually, for each dye class 12÷14 master batches are prepared with selected dyes, so as to reproduce the widest possible range of colours.
Therefore, by mixing together the various master batches in specific quantities it is possible to reproduce any colour; the master batches will be then suitably "cut" (diluted) with the cutting paste, which is a paste containing the same auxiliaries of the master batch (with same or lower concentration), but without any dye.

Dye kitchen

The dye kitchen can be manual, where all the operations for preparing the thickener, weighing the dyes and the auxiliaries, dissolving and preparing master batches and cutting pastes, is manually carried out by the operators of the dye kitchen.

This approach to work entails some problems both in terms of operators' health protection and of results; small inaccuracies, momentary distraction of the operator as well as a different way of working by the various operators can jeopardize the reproducibility of the results.
Today many manufacturers use automatic dye kitchens both for sampling and production purposes. In these dye kitchens, the various master batches and the cutting thickeners are stored in big containers, from which they are automatically collected by means of pumps to be used for preparing the cutting pastes. Special automatic distribution systems can reproduce the stored recipes (by retrieving them by means of the keyboard) and accurately weigh, blend and mix the components.

In some types of dye kitchens, the balance incorporating the container for preparing the pastes is placed on a carriage, which moves automatically under the metering heads of the containers (for cutting pastes and master batches). In other dye kitchens, the metering heads are assembled together in the same place above the balance. Later a thorough mixing will be carried out.

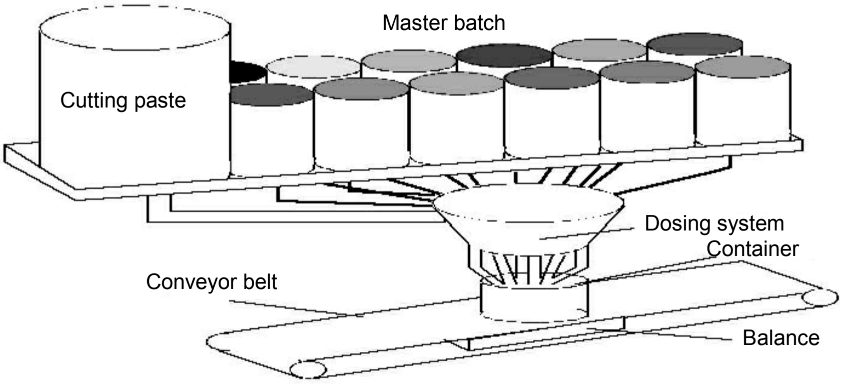


Fig. 99 Scheme of a dye kitchen

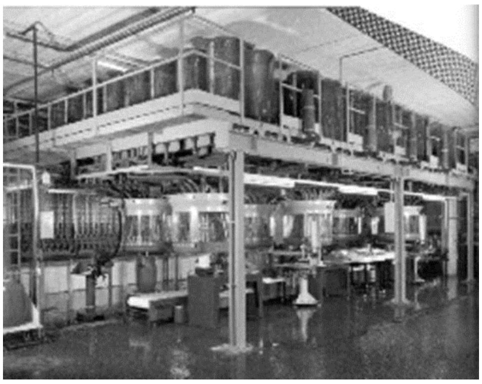


Fig. 100 Dye kitchen for production purposes

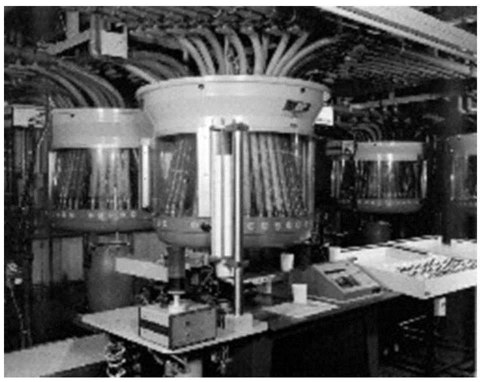


Fig.101 Dye kitchen for sampling purposes

Flat screens, sifters and hollow rollers

The printing screen is made up of a metal frame, on which a cloth (sifter) is firmly fastened in place. The cloth is usually made of monofilament or multifilament twisted polyester yarn. Three screws are incorporated on one side of the screen for centering the inward-directed cavities: one of the screws touches the block on one side and is used for warp-wise motions, while the other two screws are used both for warp-wise motions and rotations. The fabric of the sifter can have a higher or lower number of yarns per centimetre (from 40-50 to 90-100), depending on the type of fabric to be printed and on the fineness of the pattern to be reproduced.
A coating of light sensitive emulsion is applied uniformly on the cloth; the screen is then dried with a hot-air blow (40-50°C). A transparency is positioned on a sensitised printing screen; the printing screen is then photoengraved by means of special lamps: the radiations start the polymerisation reaction of the light-sensitive emulsion, which takes 120-240 seconds and makes it insoluble in water. Where the film has been blackened, radiation does not reach and does not affect the emulsion, which is not polymerised and remains soluble.
In the following washing process carried out with water, the non-polymerised emulsion dissolves, leaving the holes on the sifter open where the colour has been reproduced on the film; through these holes, the printing paste will be forced onto the fabric. After accurate inspection and manual rectification of small defects, an impermeable substance or lacquer is spread on the photoengraved cloth to enhance the resistance of the emulsion and therefore the durability of the screen. The cloth passes then on a suction opening (to remove the lacquer from the holes) and is subsequently dried.
The above mentioned operations are repeated for each colour, with as many screens as the colours.

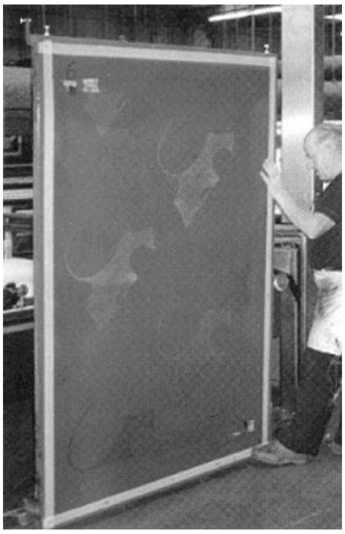


Fig. 102 Flat printing screen *Fig103 Rotary printing roller with flange*

The hollow roller is composed of a seamless nickel roller (prepared for depositing by electrolysis the metal on a special die), where the printing pastes are forced through small holes (meshes).
The number of holes per centimetre depends on the type of fabric to be printed, the design and the shades to be reproduced. The number of meshes generally used is 40 to 215 meshes/inch, corresponding to 15-85 points/cm).
In the Como district the most commonly used types of rollers have mesh numbers ranging from 125 to 185 meshes/inch, with pentagonal- or hexagonal-shaped meshes and widths ranging from 160 to 200 cm.
The cylinder diameter and consequently its circumference (which determines the pattern repeat) has fixed values, which is certainly a limit for pattern reproduction (64, 86,102, 120, 140 cm.). Costs are proportional to the width and increase rapidly as the mesh size and the circumference increase.

Printing Machines

Tables for manual flat-screen printing

These are wooden printing tables (1) with metal legs, usually 40 to 80 m long and 1 to 2 m wide; they are covered with a felt on which a resin-coated cloth is laid (2); this cloth can be covered with a polyethylene sheet coated with adhesive, which has the purpose of letting the fabric adhere to prevent the cloth from moving during the printing process (3).
An upright rail (4) is fixed on the edge of the printing table, where some blocks (5) are arranged to lock the frames, keep the pattern ratio and maintain the precise position on the table for proper registration and alignment.
The printing paste is accurately applied on the fabric by spreading it on the cloth (7) of the screen (6) by means of squeegees (or paddles) (8).
The screen centering is obtained by means of three screws; two screws are arranged on one side of the screen in contact with the rail (they lift, lower or rotate the screen) and the remaining one is arranged on one side in contact with the block (it moves the screen lengthwise).
The squeegee is moved manually.

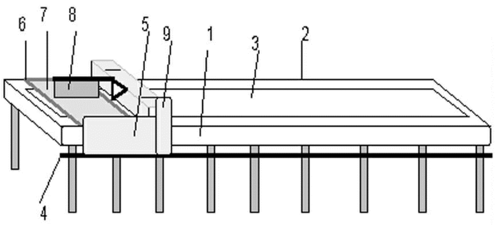


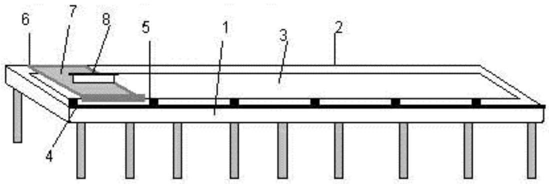
Fig. 104 Scheme of table for hand screen printing

Today this type of printing is used only for high quality products and for small lots, or it is carried out on small tables (8-10 m.) for sampling purposes.
The material is dried directly on the printing tables (30-50° C) heated by heating elements positioned under the cloth¸ with hot air jets (40-50° C.) directed on the printed cloths laid down on the table, or removed and hung above the printing table to air-dry.

Tables for flat screen printing with automatic carriages

For this type of printing, manufacturers use 40 to 80 m long printing tables, equipped with an automatic feed carriage (5) sliding on special rails; the printing screen is fixed on the carriage (6). A special device fitted in the carriage lowers and lifts the printing screen and moves the squeegee (8); the pressure applied and the number of passages are entered by the operators.
The pattern is centered by the operator by means of the set screws of the screen or by any other device arranged on the frame of the carriage moving screen warp- and weft-wise or making it rotate.
In automatic screen printing, a preset amount of the appropriate colour is released on the fabric (3) which adheres to the resin-coated conveyor belt (2) of the printing table (1); the printing paste is spread uniformly on the fabric by moving the squeegee on the cloth (7) of the screen (6); after the squeegee has passed over the screen, the screen is progressively moved to the next section and lowered again to repeat the same cycle till the end of the piece.

The screen is then replaced with another one and the cloth to be printed receives the next colour; the number of screens corresponds to the number of colours.



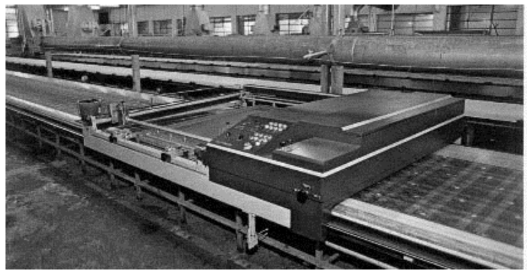


Fig. 105 Scheme of printing table with computer-controlled carriage

Fig106 Printing table with carriage

The motion of the carriage and of the squeegee on the printing tables can be controlled by electric motors, gears and chains or by means of a pneumatic system.
Nowadays all manufacturers have equipped their automatic carriages with a computer (9), on which the printing data are entered and stored; this computer control system allows a considerable reduction of operating times, labour, possible inaccuracies and errors, thus improving reproducibility.
The drying process is carried out with heated printing tables (30-50° C) or with hot air jets (40-50° C) directed on the printed cloths laid down on the table, or removed and hung to air-dry.
All the printing tables can be equipped with a rack to hang the printed cloth and a washing system after printing.
This printing method is used for good-quality small and medium yardages.

Mechanized screen printing machines

These machines (Fig. 107) include a printing table (6) with a length ranging from 20 to 35-40 m., on which a conveyor belt (3), covered with resin-coated rubber, is progressively moved. The fabric (1) adheres to the conveyor belt, after passing through a feeding system provided with a spreader (Fig. 108) and a warp-centering and straightening unit controlled by photocells or other devices (9).
The printing stations (4), which can be 8, 12, 18 or more stations depending on the length of the table and on the size of the screens, are arranged on the conveyor belt; the screens are fixed on the printing stations. Each printing station is equipped with a keyboard for setting and adjusting the printing data (5). Each time the conveyor belt stops, the screens simultaneously lower, the squeegees pass over the cloth (in line with the data entered by the operator), spread the dye, lift up and move to the next pattern repeat.
The fabric, once reached the end of the printing table (engraved with the whole pattern design), is removed from the conveyor belt and fed into the synchronised drying loft at the printing speed (8).
The conveyor belt, washed with water jets and rotary brushes and then dried (7), passes under the printing table and seizes the fabric again. Finally the fabric is wound on the beam (10).

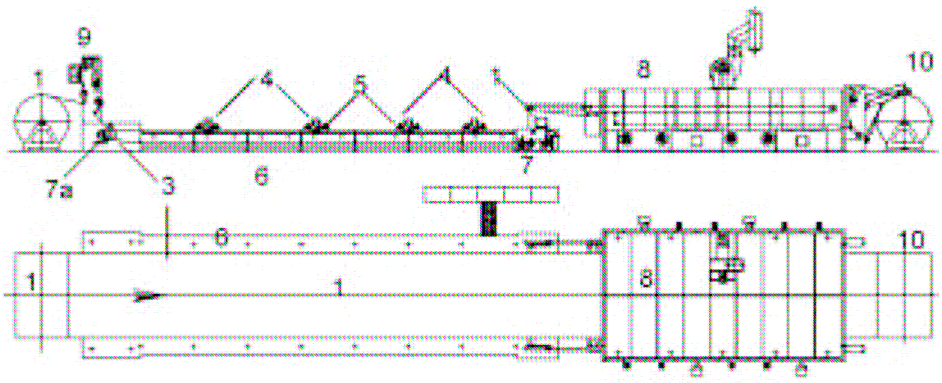


Fig. 107 Scheme of mechanized screen printing machine

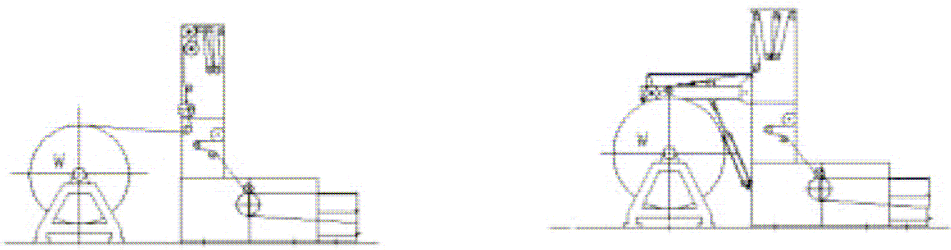
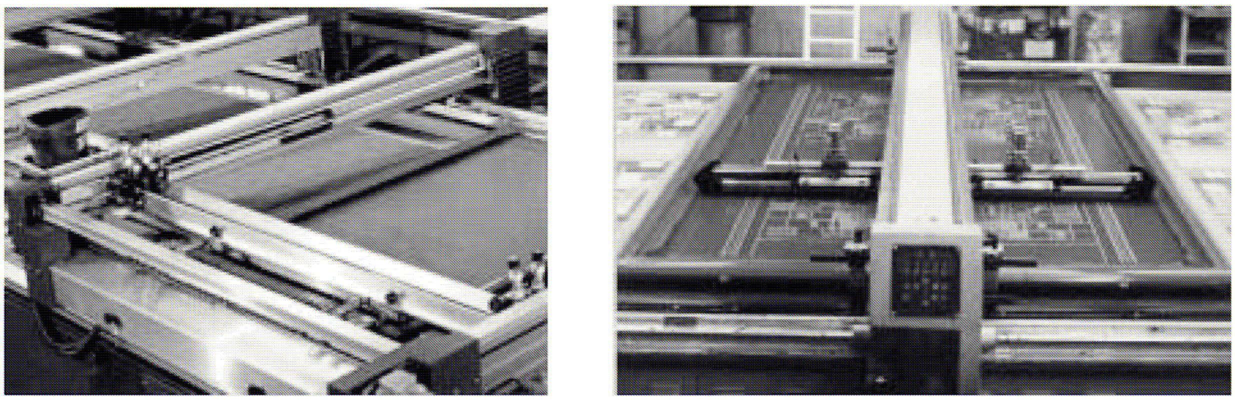


Fig. 108 Mechanized screen printing machines: feeding devices



a) open doctor machine *b)bridge-type machine*

Fig. 109 Printing stations

Fig. 110 Conveyor belt washing

Fig. 111 Mechanized screen printing machine

The main advantages of this system, compared to the screen printing carried out with automatic carriages, is an improved output rate, since all colours can be printed in one run allowing high throughput rates (maximum output ranges between 400-500 m/h). Also the printing quality is inversely proportional to the operating speed. The adjustments to be carried out before printing are time-consuming, since the printing stations must be moved progressively and carefully to the other sections or to the successive patterns.
In case of new designs or possible modifications, the printing stations must be carefully centered and adjusted to be aligned with the centering recesses.
Furthermore the screens must be removed, washed and assembled again on the printing system.
The drying process is carried out in a drying loft, i.e. inside a circulating-hot air continuous dryer positioned at the end of the printing machine. The dryer operating speed is synchronised with the average printing rate. The air blow can be adjusted at a temperature ranging from 80 to 150-160°C in order to dry, polymerize (pigment printing) or carbonize the fibres (devoré printing).

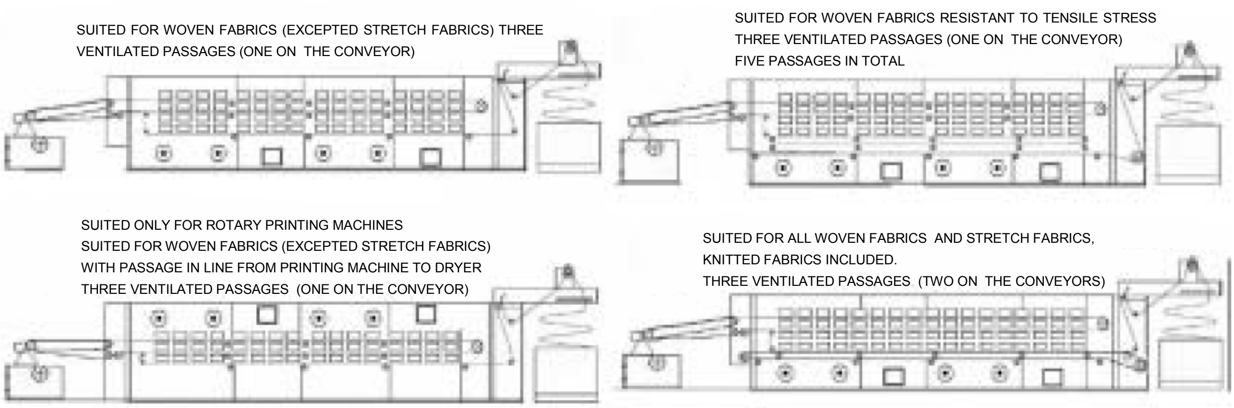


Fig.112 Drying lofts for mechanized flat printing and rotary printing machines

Flat-bed rotary printing machine (machine with hollow rollers)

This machine is used for printing large and medium yardages of medium-good quality fabrics.
The machine (Fig. 113) employs an endless conveyor belt (4) made of resin-coated rubber, on which the piece of fabric (1) adheres, after passing through a spreader and a warp straightening unit(3) controlled by photocells (2).
The printing stations (5) are arranged along the whole length of the conveyor belt (min. 8, max 12-16 printing stations depending on on the length of the printing table and on the manufacturer's needs), on which are assembled the engraved rollers (6).
The doctor knife (13) (different models are available depending on the machine manufacturers, Fig. 114) is introduced inside the photoengraved roller together with the feed unit (9) of the printing paste, which is fed by the distributor (10).

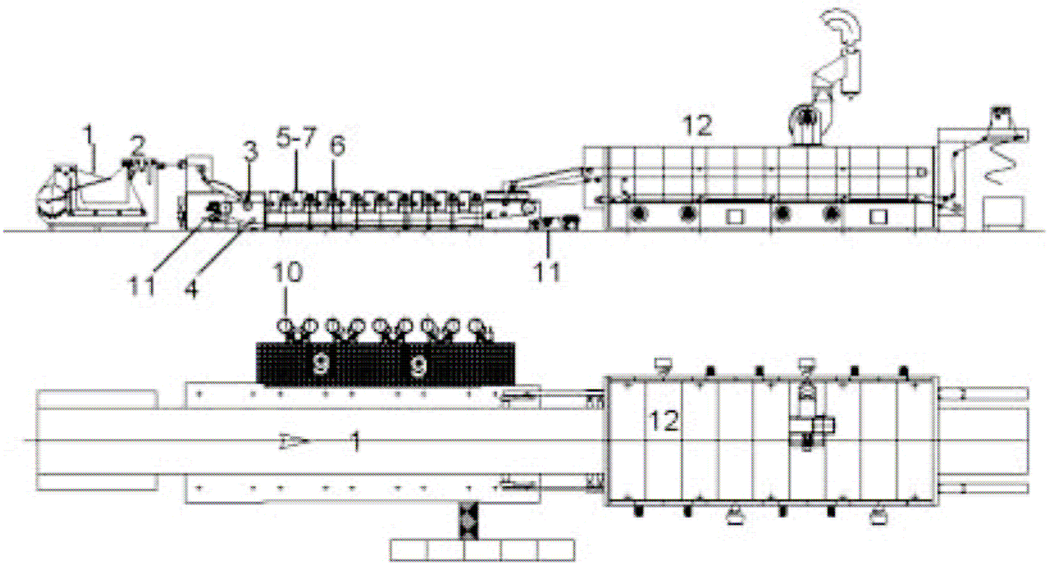


Fig. 113 Scheme of a rotary printing machine

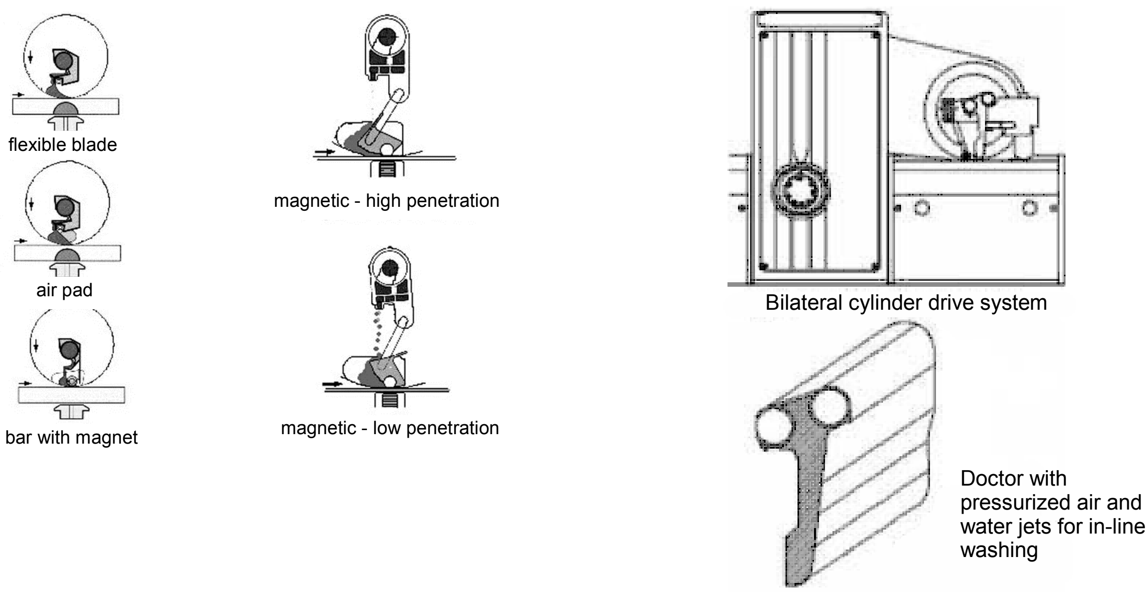
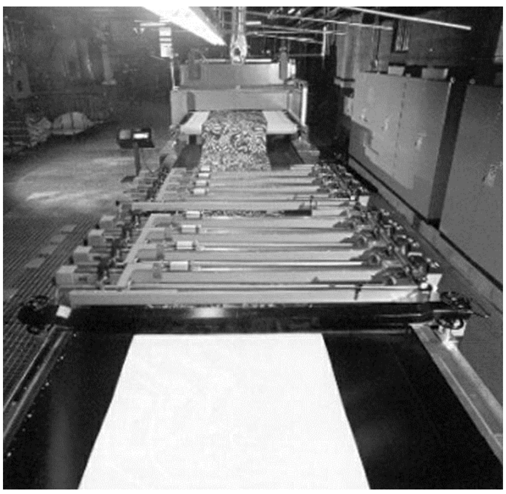


Fig.114 Various types of doctor knives



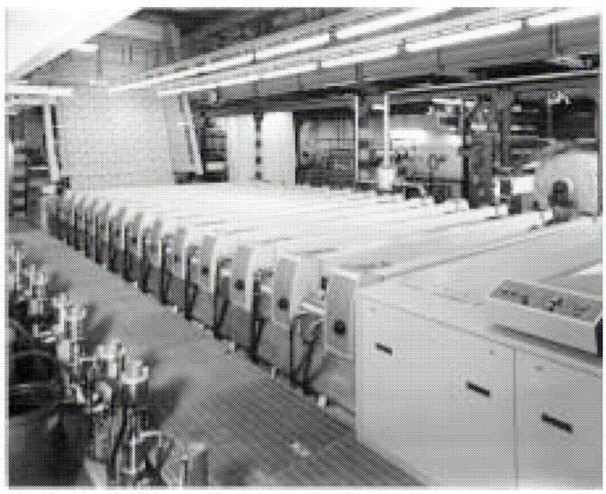
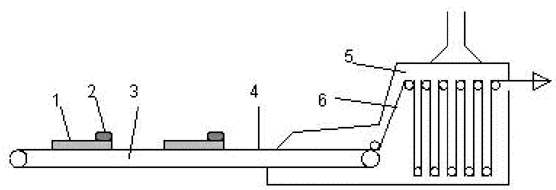


Fig. 115 Hollow roller printing machines

The rollers drop the printing paste on the fabric sliding underneath and, as the printing stations are arranged at a multiple distance from the succeeding section (usually at a distance of 64 cm.), reproduce the designed pattern.
At the end of the table, the fabric is removed from the conveyor belt and fed into the drying loft (12); the conveyor belt (11), washed with water jets and rotary brushes and then dried (11), passes under the printing table and seizes the fabric again.
The main advantages concern the output rate; in fact the non-stop process allows an average operating speed ranging between 30-60 m/min, and maximum operating rates ranging between 100-110 m/min. The complex setup and the amortization costs of older machine models limit their use to large printing runs; on the contrary, the most recent machines can be used for manufacturing cost-effective medium or small printing batches, thanks to a quick setup of the design and to a fast roller washing (to be carried out upon each colour change for every printing). Anyway the quality is inversely proportional to the machine speed.
The use of roller printing machines is limited by the pattern repeat: usually roller printing machines incorporate cylinders with a circumference of 64 cm, and therefore the pattern repeat corresponds to the circumference or to one of its submultiples (32, 16, 8). Now many manufacturers supply cylinders with different circumferences, such as for example 101.8 and 120.6 cm, with widths ranging from 1.6 to 3.2 m (the width depends on themachine model); some machines incorporate 140 cm-circumference cylinders, featuring a width of 320 cm.
Some manufacturers also supply combined machines with both rollers and screens.

Rotary table printing machines

This machine has a variable-length table (from 10 to 40 m). A conveyor belt made of resin-coated rubber slides on this table. The length of the conveyor belt ranges from 20 to 80 m., according to the machine structure and model; a piece of fabric of the same length adheres to the conveyor belt.
1 or 2 printing stations equipped with screens (and/or rollers) are arranged along the conveyor belt. On one end of the conveyor belt, a circulating hot-air drying loft dries the fabric partially at each fabric run. When the head of the fabric comes back to the printing stations, new screens (or rollers) are arranged on the table and the operation is repeated at each run for all the colours, thus making up all the colours of the pattern . After the last run, the fabric is removed from the conveyor belt to be dried thoroughly, the conveyor belt is carefully washed and a new printing cycle can be started.



1- Printing stations (screen or roller printing systems)
2- Keyboard for data input
3- Table
4- Resin-coated conveyor belt
5- Drying loft
6- Path of the fabrics at the end of the printing process

Fig. 116 Scheme of rotary table

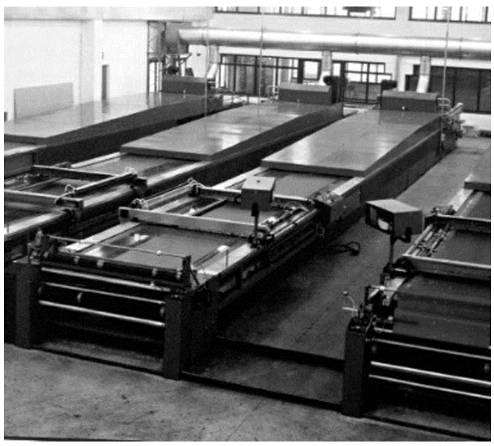


Fig. 117 Rotary table

The operating mode of this machine is partly similar to the rotary system, and partly to manually operated machines and screen printing systems; it is used for high quality small/medium lots or for samplings for rotary and/or manually operated printing systems.

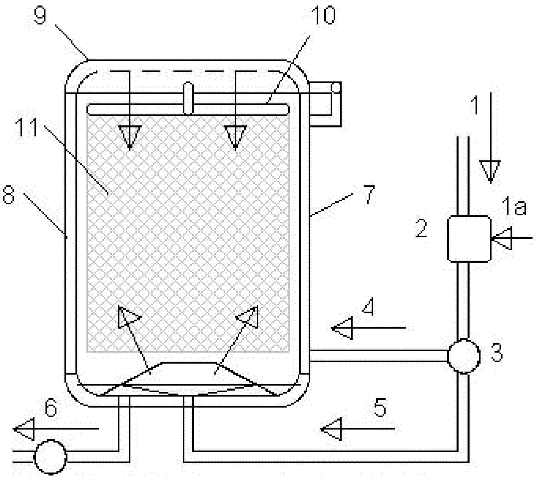
In the printing field, very few mechanical innovations have been introduced in these last years; anyway, small mechanical improvements and the coming up of electronics have allowed excellent quality results also on machines with high output rates. Furthermore these improvements have remarkably cut stand-by times, labour costs and energy, water and auxiliaries consumption.
Here are some examples:

- Conveyor belt washing system with water recycling.
- Automatic synchronisation of printing speed and drying speed by means of inverter controlled by special processors.
- Automatic adjustment of the exhaust units of the drying lofts, to maintain the best drying conditions.
- Holding systems to maintain the roller or screen centering, which must be adjusted in case of a slight shifting of the conveyor belt (±0,03 mm accuracy).
- Synchronisation of the roller speed with that of the conveyor belt; it can be slightly modified depending on the fabric.
- Automatic transfer progressively moving to successive stations on manually operated machines controlled by a computer.
- Storage of all printing options for the different patterns and colours (ratio, travel, speed, pressure and inclination of the doctor knife or squeegee etc.).
- Feed distribution of the printing paste in the various sections of the roller, depending on the printing paste consumption.
- Roller washing carried out directly on the machine (in 8-10 minutes) to change the pattern variant.
- Roller machines allowing removing and assembling the rollers with the doctor knives when the pattern is changed, with a remarkable reduction of operating times.

Steaming Machines

Static steaming machine (Star type)

This steaming machine is the oldest steaming system. It consists of a cylindrical heater with a jacket to allow the steam to be blown from the top and the bottom of the cylinder (the steam heats the walls avoiding the formation of drops of condensation). The cover is sealed hermetically to allow the machine to operate under pressure.
The fabric is firmly hung by its selvedges and is fixed to a special back cloth (bengaline). The whole is wound on a star-shaped carrier by means of hook-shaped pins. The carrier with the fabric are loaded into the heater; steam is then forced into the heater removing the air from it. The cover is then closed and the pressure is kept constant by introducing or extracting the steam. Once the steaming process has been carried out, the cover is opened, the carrier is unloaded and the fabric is removed.



1. Steam feeding system – 1st moistur. water
2. Saturator
3. Steam feeding setting.
4. Steam from the top
5. Steam from the bottom
6. Steam exhaust
7. Steaming machine body
8. Jacket
9. Sealed cover
10. Star
11. Fabric + bengaline

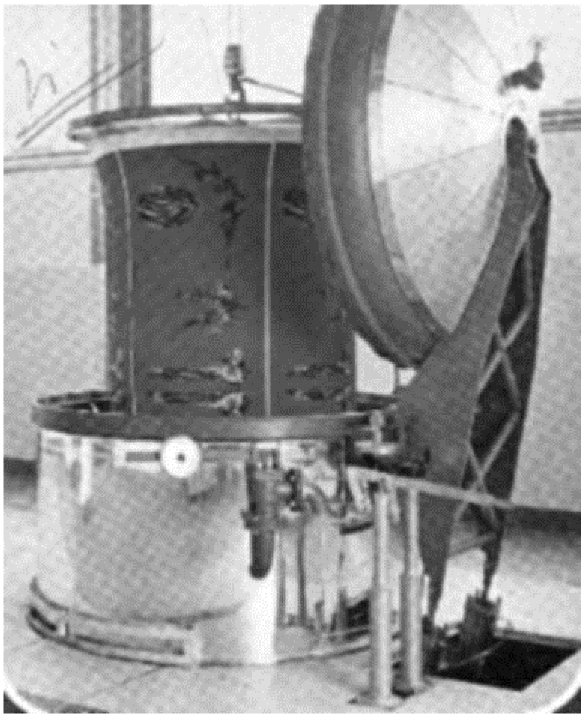


Fig.118 Static steamer

Due to the poor steam exchange, this system is not suitable for discharge-printed fabrics. On the contrary, it gives excellent results with man-made fibres, since it allows working at temperatures ranging between 130 and 135°C and at pressures of 1.8 bar (i.e. with dry saturated steam and high temperature). This system gives a good dye yield, but possible end-to-end evenness defects (when forced incorrectly, the steam stratifies at different temperatures and with different moisture contents; therefore colours are fixed more consistently in the lower end of the fabric).
This system is now rarely used, since only small lots can be treated (max. 400 m long cloths are treated in 10-60 minutes) and many operators are required, thus entailing high costs.

Continuous steaming machine

It is made up of a parallelepiped-shaped container (recent systems have closed bottoms, while old ones were opened at the bottom) with double-wall structure, preventing external heat transmission.
In the lower part of the jackets the steam, coming from the boiler and passing through the saturator, is caused to expand and boil in water. In this way, the saturated steam at atmospheric pressure raises and heats the walls and the ceiling of the jackets (preventing condensation drops from forming and dripping onto the fabrics, as a result avoiding possible defects). The steam lowers from the top of the steaming machine through the ceiling openings, drives the air away (air is heavier than steam) and fills the steaming machine.
The equipment to control moisture and temperature of the steam feeding the steaming machine is positioned in the jackets; the real-time control devices work interactively and start immediately some spray-water humidifiers, cascade-connected with superheaters, also assembled in the jackets. Thanks to this system, all the variables can be controlled in real-time (the temperature difference allowed is ±0,5°C of preset values, and steam density between 96 and 98%). If necessary, the steam can be heated at temperatures of 170-180° C at atmospheric pressure passing through the jackets.

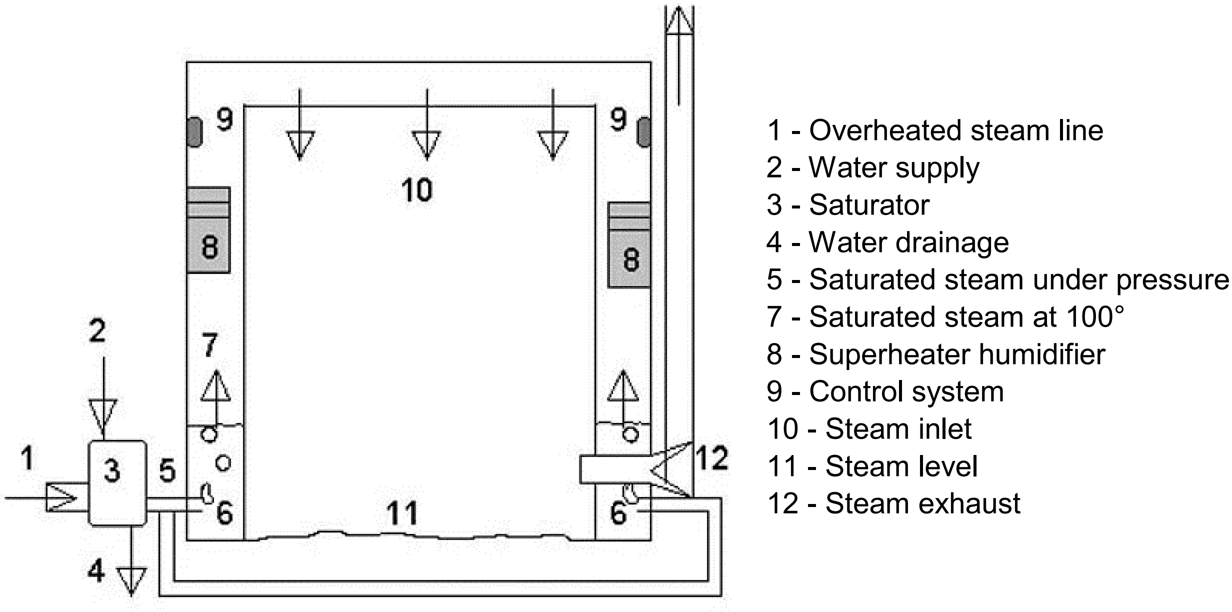


Fig.119 Scheme of a continuous steaming machine

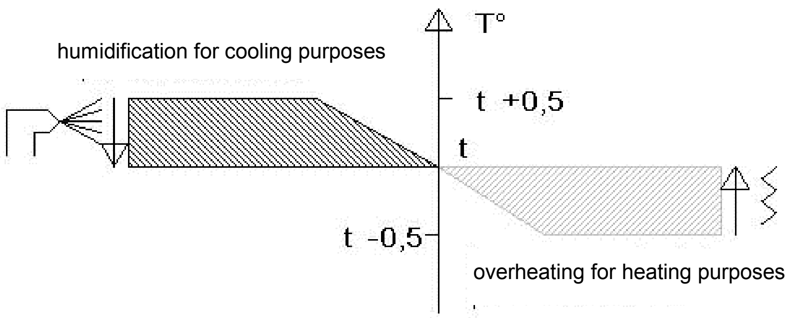


Fig. 12 0 Temperature control

The fabric passes through the steaming machine folded on sticks; the sticks rotate all along the path and change the contact point with the fabric continuously, to prevent any fixation defects in contact points. Furthermore the fabric, in consequence of the rotation of support sticks, changes constantly its position to reduce the formation of defects due to possible steam stratification. The steam exchange is carried out by means of one or more exhausters. At the end of the path, the fabric gets out of the steaming machine, while the sticks pass in the lower part of the machine and grip another piece of fabric at the entry of the steaming machine. Special inlet and outlet devices, together with a slight pressurisation, prevent the air from entering (max. O_2 contents allowed = 0.3/1000 in volume).

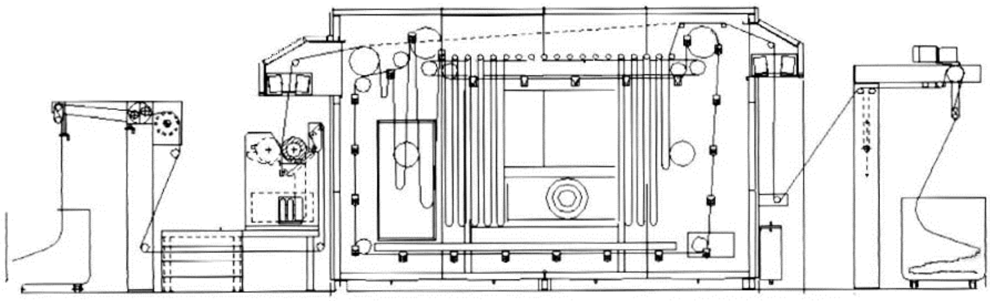


Fig. 121 Scheme of a steaming machine (the fabric moves in laps or on sticks)

The continuous process allows a better output capacity and a reduced number of operators; the costs are therefore lower than the static steaming machine. It can be used for all kinds of print by opportunely changing the operating conditions and gives better results, above all in discharge printing, since it allows the removal of decomposition gases generated by reducing agents and a better temperature control, thanks to the huge exchange of steam.
For this purpose, all the steaming machines built in those last years have closed bottoms; this gives a better control of process variables (temperature, pressure, moisture, oxygen, steam circulation and exchange) and allows the creation of a slight pressurisation to prevent oxygen from entering.
The operating speed depends on the quantity of fabric in the steaming machine (number and length of the fabric laps), on its width (it is possible to steam two fabrics simultaneously) and on the time necessary for fixing the dyes; these values also determine the steam requirement and exchange.
To offer the customers a wide variety of steaming machines, manufacturers have designed models in different structures and sizes, equipped with special devices to control the moisture of the fabric fed into the machine (water atomizers), the steam fed into and extracted from the machine, as well as all the other process variables.
Some continuous machines for folded pieces can also be used for quick steaming cycles (from 1 to 2 min,) by moving the fabric on the sticks; in this case it could be useful to use flash steaming machines with short fabric paths.

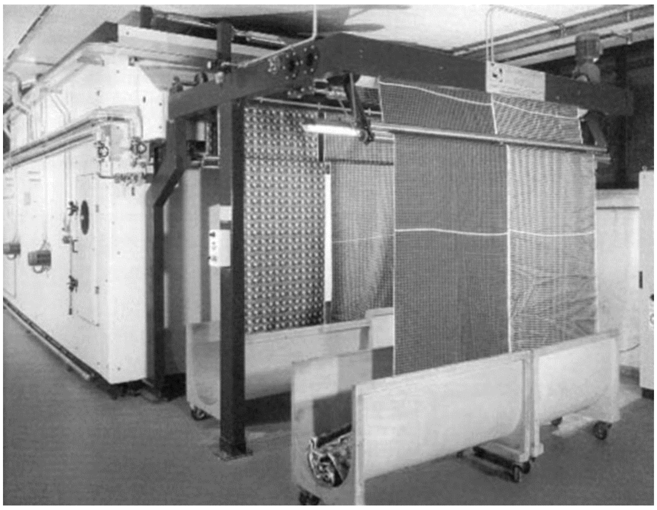


Fig. 122 Continuous steaming machine

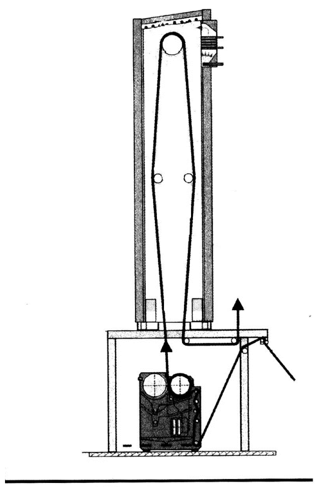


Fig. 123 Flash steaming machine

Washing machines for printed fabrics

After printing and steaming, the pieces have a rough hand due to the use of thickeners, and the colour shade is not the final one.
The washing process aims at removing the thickening agents, all chemical auxiliaries and the unfixed dye remained in the thickener or passed into the fabric.
If correctly carried out, the washing process can enhance the colour brightness to obtain the maximum fastness for both fibres and dyes and offset the fabric tensions.
Obviously the washing process must not affect the fabric (felting or other negative alterations of the fibres, change of dimensional stability etc.), as well as the printed patterns (undesired colours must not affect white or unprinted fabric section or areas printed with light colours, while the dyes removed with the washing process must not affect the colour shade).
To obtain the desired results, a powerful washing is not sufficient: dissolving dyes (conditions similar to the dyeing process) do not fix on fabric sections printed with different colours, do not dye or bleed on white areas.

That is why it is important to select the right components, namely:

- washing machine
- conditions
- auxiliaries,

bearing in mind that the results obtained are also the outcome of all upstream operations.
To optimize the washing of printed fabrics, an accurate evaluation of all process steps is also fundamental; we can point out three basic steps, different but nevertheless overlapping:

Step	***What happens***	***What makes the operation easier***	***Measures to be taken before washing***
1	reimbibition and thickener swelling	- quick and high absorption of the liquor - presence of wetting agent - contact time	- type and quantity of thickener - thickener stability to steaming
2	release, dissolving, removal of thickener and dye	- mechanical action - squeezing - suction - water exchange	- quantity and type of thickener - dye fixation degree
3	exchange, dilution, dispersion of unfixed dye	- temperature - detergent - dispersing agent - time - dye - alkali + reducing agent	Dye selection

Step 1:
The thickener film, when touching the washing liquor, rehydrates, swells and progressively reduces its viscosity. At the same time, water solubilizes or dissolves part of the dye remained in the thickener and, by penetrating the fibre, starts solubilizing the unfixed dye.
The presence of a suitable wetting agent in the washing liquor and the possibility to direct powerful jets and liquor atomised mist on the fabric, accelerates the wetting step, while a correct contact time of the material with the dye facilitates this step; the thickener swelling completes the dye dissolving.

Step 2:
Once the correct viscosity degree has been achieved owing to the powerful action of water jets, to vibration, squeezing and/or suction, most of the thickener dissolves along with the dye and the auxiliaries inside it.
Simultaneously, part of the dye remaining on the surface of the fibre or dispersed but unfixed inside it,, dissolves or diffuses in the liquor.
During this step, the dye reaches its maximum concentration in the washing liquor (which becomes very similar to a dyeing liquor); it is therefore extremely important to work at low temperatures to avoid conditions that could facilitate the dispersion of the dye in the fibres; the washing liquor should be quickly withdrawn from the contact with the fabric to protect white ground tones.
These first washing steps are of utmost importance, since they can lead to the elimination of more than 80% of thickener and unfixed dye, but it is fundamental to work at low temperatures and to avoid continuous and protracted contact of the fabric with the liquor. This grants an optimum

protection of white grounds also during subsequent hot washings; the dye eliminated through a cold process will affect the fabric in subsequent hot treatments.

Step 3:
At this point it is essential to eliminate the remaining 15-20% of thickener still fixed on the fibres and to restore the fabric's original handle; it is also an absolute exigence to eliminate simultaneously the dye which is not suitably fixed on the fibres and to obtain the highest possible wet and rubbing fastness.
In the case of natural fibres, it is recommended to operate at the highest temperatures allowed by the various fibres (which obviously depend on the material to be processed); an appropriate dwelling period for the fabric before the powerful hot washing stage facilitates the swelling and the dissolution of the thickener blocked in the fabric and the elimination (by diffusion) from the fibres of the dye which passes to the diluted liquor solution. The low concentration of the dye (if the two first steps are carried out correctly) and the high temperatures reducing their affinity level, as well as the use of suitable dissolving agents and detergents protect the white grounds of the fabrics from being affected. For synthetic fibres and particularly for polyesters printed with dissolving agents, the dye on the surface is destroyed by means of reducing alkaline liquors at 70-80°C, always with a suitable dissolving agents. The most part of the dye contained in the thickener should be eliminated during the first and the second step; in fact, to destroy the dye not fixed on the fibre or remaining on the surface it is necessary to continuously add alkali and the reducing agent (these continuous additions could be excessive, due to the presence of the dye remained from the previous steps). At this point, the fabric goes through a hot soaping treatment.

Step 4:
Rinsing and/or neutralisation.

The second step includes the choice of the most suitable washing machine.

Washing can be carried out:
- with an overflow system (rarely) or in winch machines (rope discontinuous washing, which can ensure good final results, cost efficiency and high output, must be evaluated for each specific condition).
- in winch machines equipped with various vats (continuous rope washing), or continuous washing units: this kind of washing can grant high output and cost efficiency, but often the quality is really poor).
- in continuous open-width washing units for printed fabrics.

The washing process is often considered a real bottleneck in the finishing cycle, but a reduction of the washing times will certainly lead to poor results (inevitably entailing a further washing stage with resulting loss of time, increase of costs, delivery delays and possible fabric damage).
These machines are designed for washing printed material and are equipped with all possible systems to avoid the most common problems (duplications, contamination of ground colours, etc.).
The most successful systems are continuous open-width machines; they assure the best washing results. In recent times, combined machines (with an open-width washing section and a rope washing section) ensure excellent washing results and also optimum hand for some types of fabrics.

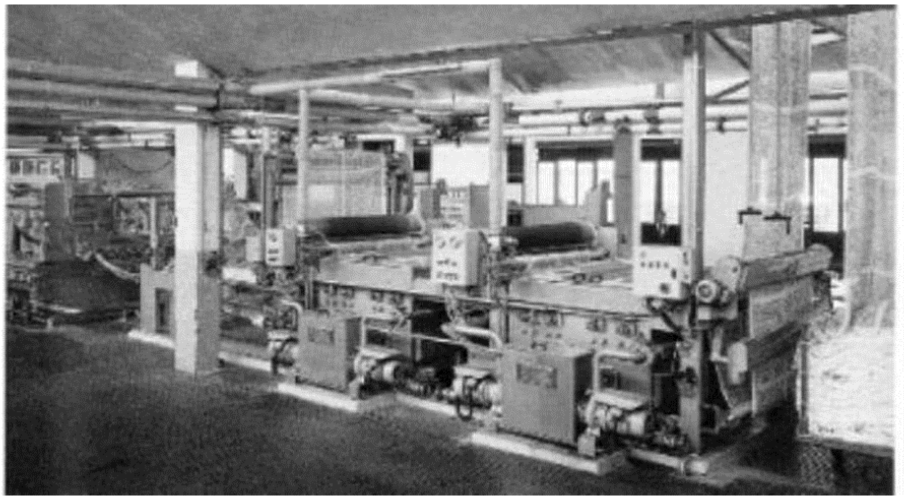


Fig. 124 Scheme of a continuous open-width washing range

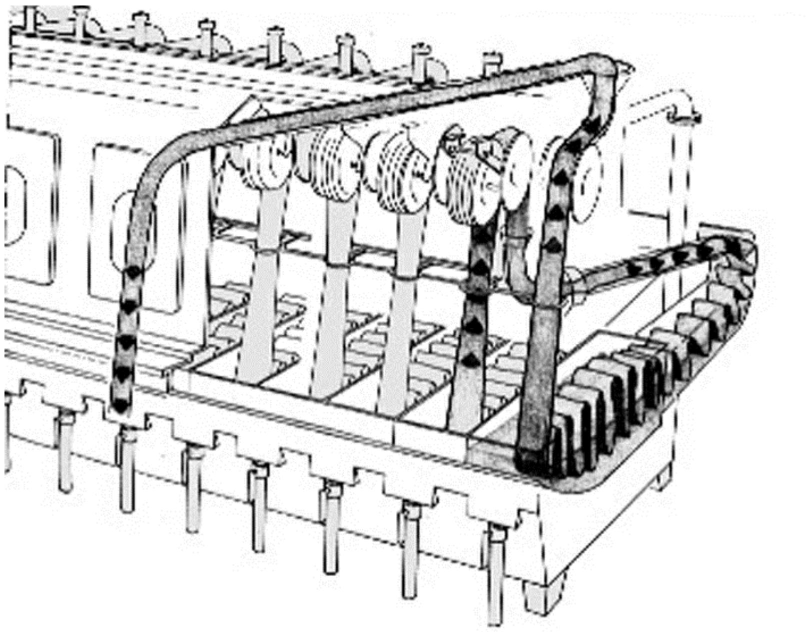


Fig. 125 Continuous rope washing range

Let us examine two of the most used and versatile open-width systems, which can be used both for pre-treatments (desizing, scouring) and for washing after dyeing and printing. Fig. 126 shows the scheme of a treatment unit of the first mentioned type, where the fabric, thanks to a vertical double-positioning system, is exposed on both sides to the powerful washing action of the overheated liquor. The complete and quick removal of soluble products and dissolved solid residues is performed by the action of the bath (with high kinetic and thermal contents, at 105°C) sprayed by water jet nozzles assembled on the whole width above the upper grooved cylinders (Fig. 113); at the same time the shape of the grooved cylinders directs the washing liquor laterally and forces it powerfully through the fabric.
The washing system operates with a reverse flow of the liquor (counterflow washing) on more washing units; in each unit the washing liquor is filtered before being fed to the superheater by the pumps.
A PLC (displaying the parameters on a special screen) controls, regulates and monitors every process.

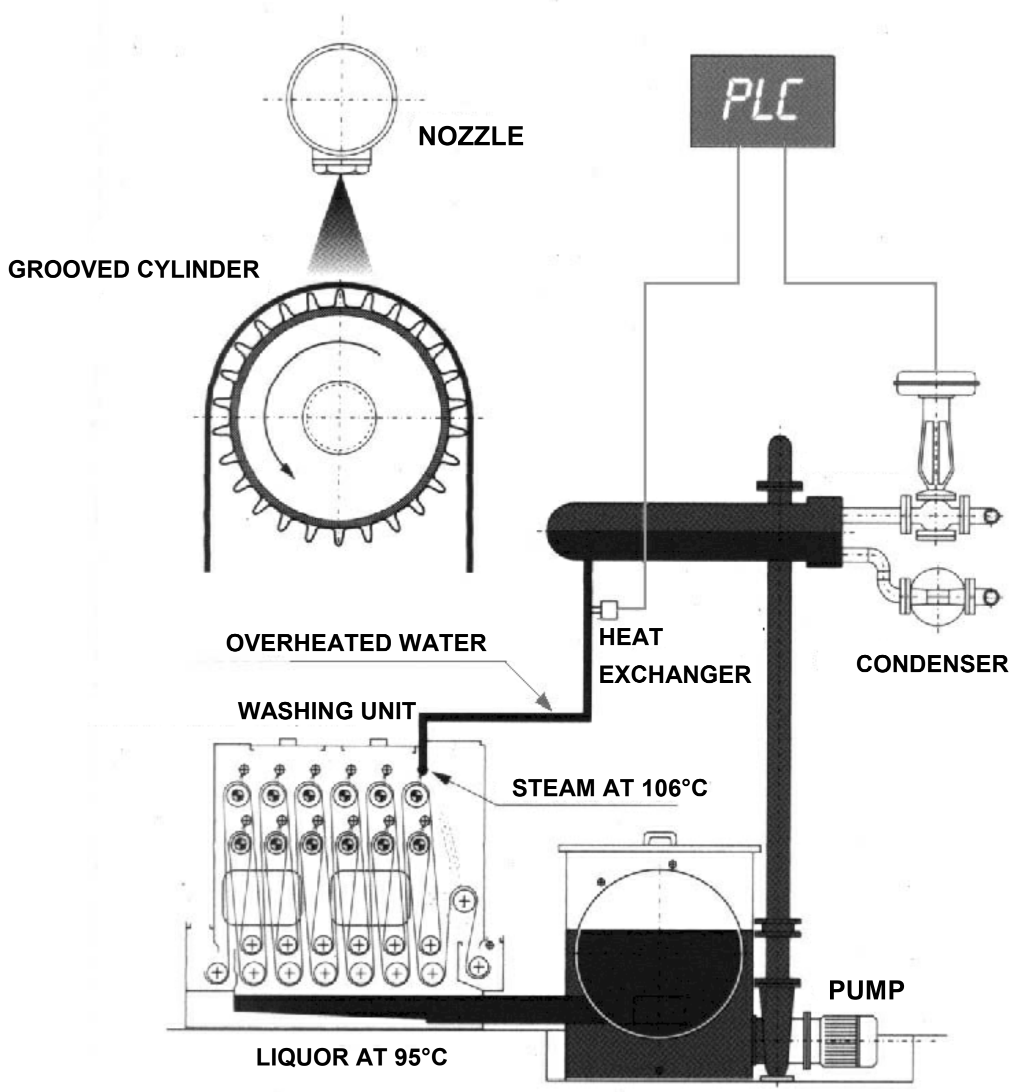


Fig. 126 Scheme of a washing unit with upper grooved cylinder.

An accurate dimensioning of the system associated with a correct set-up grants an optimum degree of reliability in terms of results, thus keeping water consumption low and the output rate good.
A thorough control and a suitable choice carried out during previous steps also allow considerable reduction of polluting waste water.

The selection of the right washing auxiliaries is another crucial step: a good wetting agent can accelerate the rewetting phase of the thickener, thus facilitating its elimination in cold processing conditions and in relatively short times.
Since the elimination of the thickener and of the dye can be carried out completely in cold processing conditions, high temperatures can be used only in the subsequent steps of the process.
These conditions cause a dangerous increase of dye fixing speed f, which could entail the possibility of affecting white grounds.
Suitable dissolving agents of anionic-nonionic or nonionic detergents can bind the dye, stabilising it as a solution or dispersion, also in relatively high concentrations.
This allows a good and smooth protection of white printing grounds. Another important feature is foam creation: a low foaming capacity avoids or reduces the use of anti-foaming agents, with consequent advantages.

To conclude, washing conditions strictly depend on type of printed fabric, type of fibre and applied dyes.

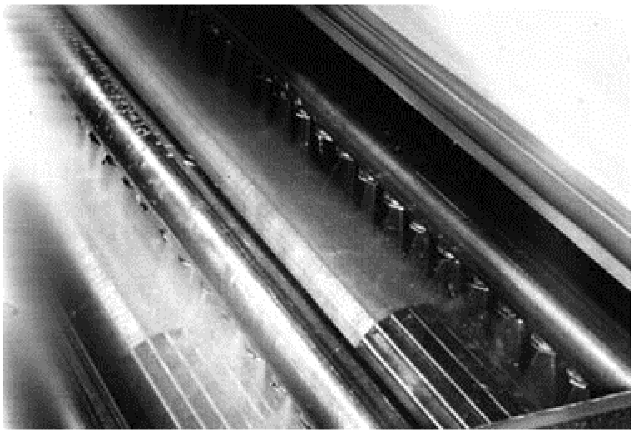


Fig. 127 Detail of the washing unit

Fig. 128 Detail of the spraying nozzles

The second line (Fig. 129) is composed of four units in which the fabric, while passing on a pair of large diameter perforated drums, is struck on the back by four sheets of water. The large discharge of low pressure water permits to remove quickly the less soluble substances, although treating the fabrics very delicately.

The possibility of automatic adjustment of drums and cylinders speed, the presence of rocking rollers, the position of the relaxation storage vat between the first two washing units and the subsequent washing units, permit to run at an extremely low pressure and consequently to process practically all types of fabrics (woven, stretch, knitted, of every kind, with the exception of tubular not cut knits).

The presence of a programmer permits to program and control all functions and operating variables typical of a continuous washing line (processing speed, tensions, temperatures, pH, water exchange, auxiliary metering, etc….) and, on request, to display all operating parameters.

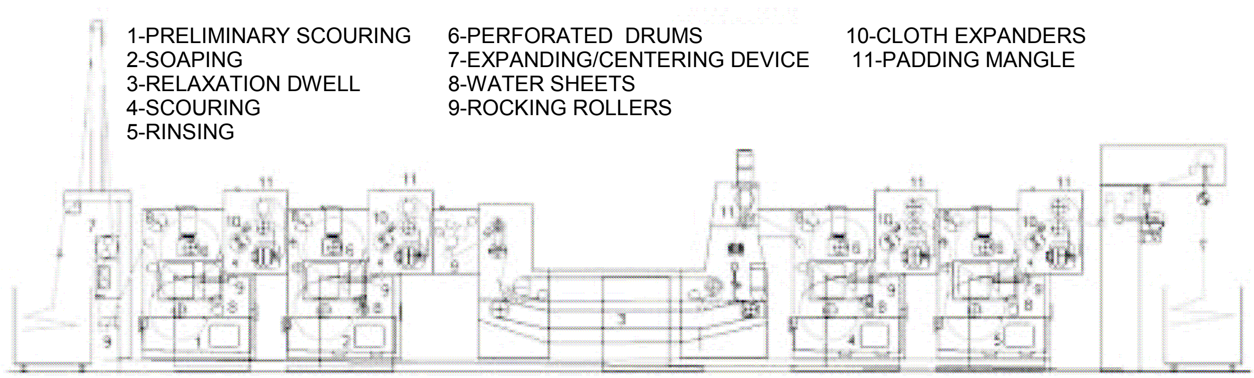
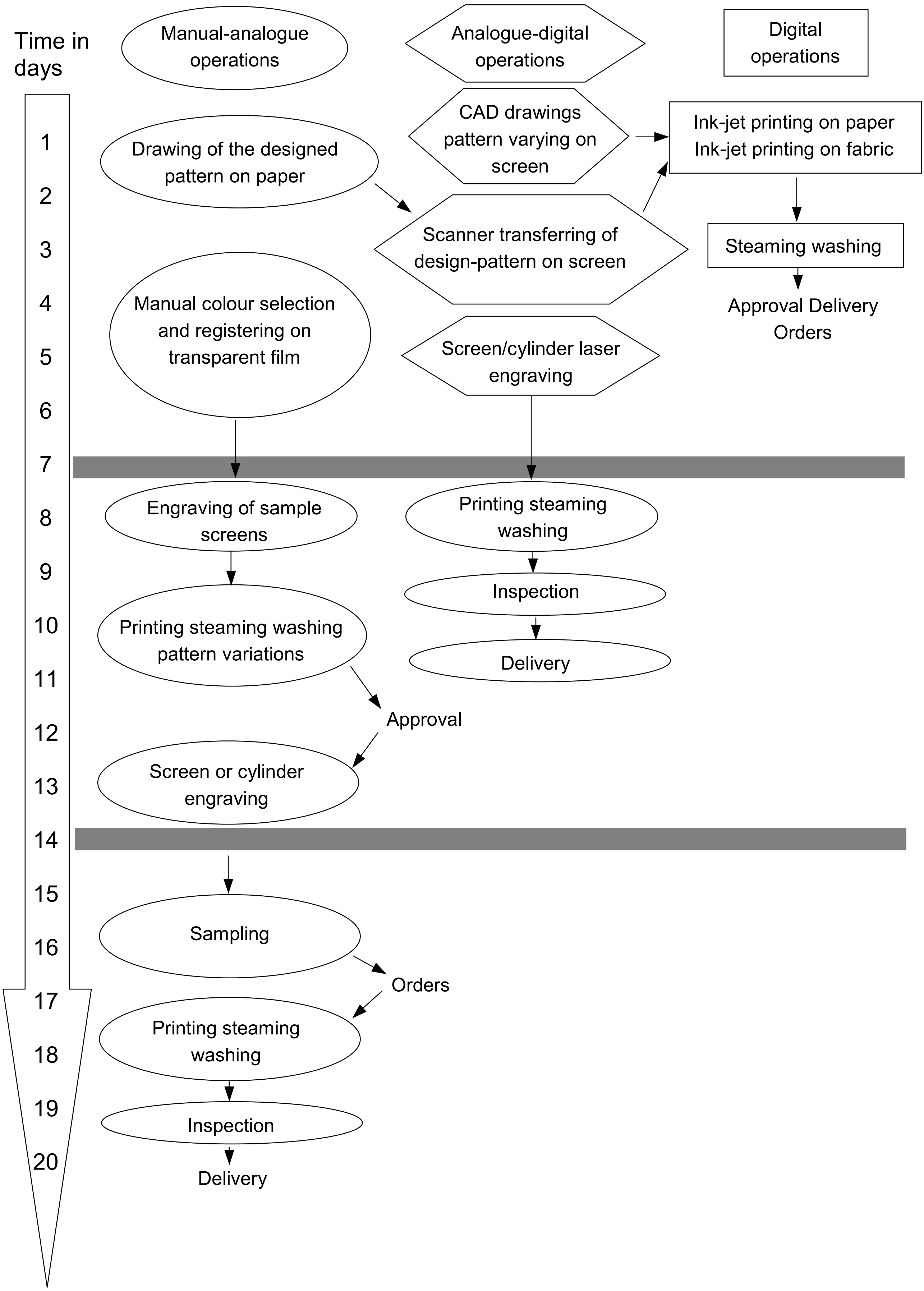


Fig. 129 Open-width continuous washing machine

Developments in screen/ cylinder engraving and textile printing techniques



The traditional engraving of printing screens and cylinders is carried out through following operations:

- schemes are sketched on paper (manual operation);
- colours are selected and a transparent polyester film is prepared for each colour to be printed, and the (continuous) design is registered (the operations are carried out by hand and/or by photolithographic process);
- small panels are engraved for the pattern variants;
- colour variants are printed on the fabric with sample screens, and then steamed and washed;
- the customer approves the pattern and its variants;
- the screens or cylinders are engraved (traditional photoengraving with photosensitive gels and transparent films);
- sample printing, steaming and washing;
- production fabric printing.

For over a decade, patterns (sketched directly with a computer or scanned and eventually modified) have been digitally reproduced by means of CAD stations. With digital images and dedicated programs, registering operations and colour selection (transparent films are created/stored on a computer), the process has been considerably shortened and simplified. Furthermore, thanks to the possibility of manipulating schemes on a computer and reproducing them in the form of transparent films, every pattern variant can be made directly on the screen (with an extremely quick operation) or printed on paper and submitted for customer's approval (unfortunately colours are reproduced almost roughly and the fabric cannot be really touched, but the operation is carried out in a few minutes).
Now printing times and (partially) costs have gone further down thanks to the latest innovative technologies such as powerful lasers, investment casting and, recently, cold laser (which directly engraves cylinders or flat screens).

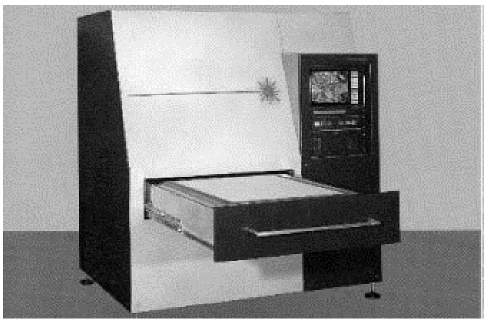


Fig. 130 Screen engraving laser

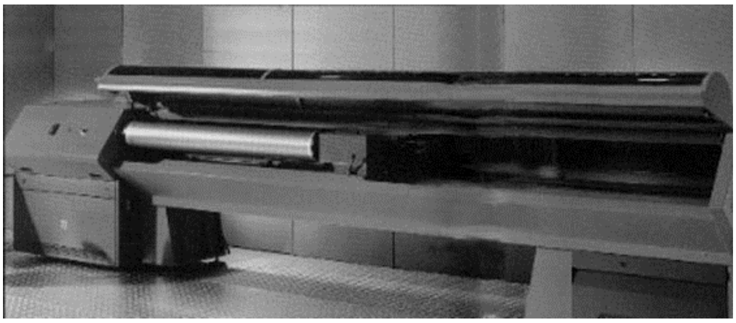


Fig. 131 Cylinder engraving laser

It is however still necessary to engrave panels and cylinders to print the final pattern on the fabric and to submit it to customer's approval: these operations need more time than what the fashion sector can afford to wait. Also basic costs for making and storing panels (some designs will never be sold) make this system particularly expensive and difficult for printing today's most required small yardages.
An important step forward to partially solve these problems has been made with ink-jet printing techniques.

Ink jet printing

The digital printing technology allows to print fabrics, in particular silk fabrics, cellulosic fabrics (cotton, viscose, linen) and polyester fabrics, but also silk/cotton and silk/viscose blended fabrics, as well as polyamide and PA/elastane fabrics, by means of "inks" based on proper reactive, acid and disperse dyes, in which cases fabrics need to be suitably prepared for this particular printing; these substrates in pure or blends, even if not properly prepared, can be printed in some types of patterns with pigment dyestuffs with satisfactory quality results. For the time being, this system is used mostly to prepare samplings and, more and more often, to produce small and, whenever necessary, customized lots. Short production times are undoubtedly the main advantage for choosing this printing method: in 2-3 hours it is possible to pass from pattern to print production with speeds ranging from 3 to 30 sqm. per hour with the most common and low cost plotters, or with a productivity from 8 to 60 sqm/hour with the machines suited for small production lots, until a maximum speed of 30 to 150 sqm/hour with industrial high cost ink-jet machines (minimum and maximum speeds on the same machine depend on the pattern, on the type of substrate and and on the quality results desired); we cannot however but mention also the possibility of producing photographic images which cannot be reproduced with traditional printing techniques and which are no doubt better than four-colour screen printing.
Ink-jet printing is a direct printing technique which permits to "imitate" the patterns obtainable with the traditional direct printing, in both versions of resist and discharge printing. Printing effects such as foil effect, relief pigment, glitter effect, metallized effect, etc. which can be obtained with the traditional printing technique are with ink-jet printing not possible.

Digital printing principle

The basic difference between traditional printing and ink-jet printing is that this last technique is a "no-impact" printing (colour transfer onto the fabric takes place without any contact), with an ensueing series of advantages and disadvantages (diversities) in respect to traditional printing (where colour is deposited on the fabric by means of screens/cylinders and doctors).
With digital printing, tiny ink (dyestuff) drops in different tonalities (from minimum 4 to max. 12 shades) in water solution are projected onto the fabric (almost at the same time and in controlled sequence) and combined together or are positioned side by side on the fabric, in order to reproduce the original pattern.
The printing operation must be preceeded by fabric pre-treatment and followed by steaming to fix the dyestuff and by washing (in case of pigment printing, a polymerization is necessary in place of pre-treatment and washing operations).
On the basis of the above, we can pinpoint immediately some advantages and some problems connected with this technology:

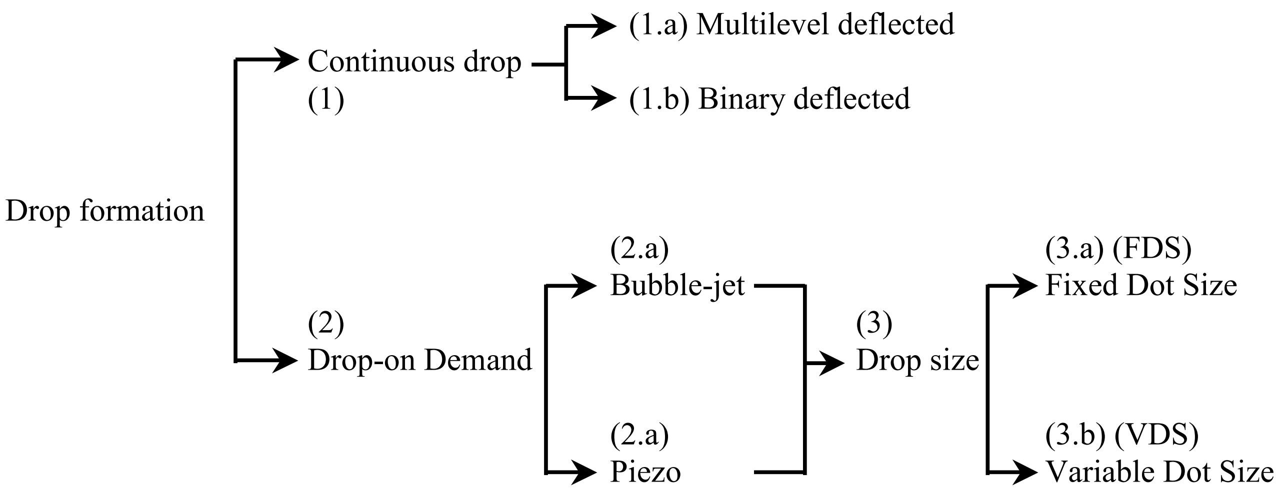
Advantages:
- contrarily to traditional printing, screens or cylinders are not required, therefore manufacturing costs, depending on pattern size, tracing type and number of pattern colours, can be spared
- in few hours (and no longer in the course of days or of weeks as in the past) patterns in all desired colour tonalities can be printed
- limited production lots do not affect excessively the costs, and it is at any moment possible to introduce small changes or to personalize the patterns
- not to be neglected from the ecological and cost-effectiveness points of view is the fact that dyestuff, thickener and auxiliaries are used in quantities as small as strictly necessary, thus avoiding residues of printing pastes prepared in excess with traditional printing and the consequent disposal problems.

Disadvantages:

- The production of large lots requires, and probably will require still for some years, the use of the old technology (medium-size lots could be produced already with ink-jet printing).
- Owing to the low viscosity of printing inks, if we want to avoid the widening of print edges caused by the capillarity of the textile substrates and to ensure a perfect pattern definition, we must properly prepare the fabric by applying thickening and auxiliary agents (same as commonly used in traditional printing) and successively dry the fabric.
- The poor, or better said variable, penetration of the color drop into the fabric can lead to considerable differences between the right side and the reverse side of the fabric, therefore this printing technique is used in specific fields where these “defects” can prove advantageous.
- The use of a limited number of colours (generally 6 to 8) leads to a reduction of colour space
- The cost of the inks is today still rather high
- The difficulty in colour reproduction when passing from ink-jet samplings to traditional ink-jet production.

Drop ejection technologies

The drop ejection technology is the basis of ink-jet printing.
Whichever ejection technology is used, nozzles are always present; they are mounted on a printing head which moves on a carriage in the direction of fabric weft (Y axis), reproducing during their passage a pattern band of variable size. A further pattern band will be reproduced with the subsequent passage of the carriage, after the forward movement of the fabric in warp direction (X axis) which depends on the size of the printed band.
We can classify the technologies for the application of the drop onto the substrate according to different methods:



The drop formation method

1.Continuous drop:

Continuous multilevel deflected ink-jet method

The main characteristic of this technology is its capability of shooting a thin ink jet which during its course, owing to superficial tension, forms small drops. The drops take up an electrostatic charge of size variable according to the desired angle of deviation, resulting from the passage through a

magnetic field. The diverged drops are projected onto the fabric; the not diverged drops fall on the contrary into a suitable container, where they are recovered.
It is therefore possible to have an extremely quick sequence of drops projected at high speed, which permits to print each time a pattern band and not a single line and consequently to obtain a fairly good printing speed. The printing quality is however not very high; maximum resolution is 240 dpi, and also the printing accuracy is limited by the precision of the drop deflection.

Continuous binary deflected ink-jet method
Drops are generated as per previous method, but in this case the drops having a straight course (not electtrostatically charged drops) are allowed to fall on the fabric, whereas drops not necessary for printing (electrostatically charged drops) are diverted from the magnetic field and recovered.
A characteristic which the two techniques have in common is the necessity to use high conductivity inks, although not very complex. The duration of the printing heads is quite low; the jets show a strong propensity to breakage and also a certain tendency to the formation of deposits in the loading and deviation plates; this jeopardizes machine reliability.
Owing to abovementioned reasons, this method is not frequently used for textile printing, but finds wide application for poster designs, labelling, etc.

2.Drop-on-demand
The nozzle creates the drop on demand, that is when it is needed.
With this technology, drop speed proves limited (10 to 15 m/s), so that it is impossible to obtain a quick print (unless the nozzle number is increased),but on the other hand printing heads are simpler and more reliable; moreover higher operating precision and better printing results can be attained. In fact this is the digital printing technology which normally finds application in the textile sector.
Also in this case, for drop creation two different methods are used by the nozzles, with consequent differences as to head size, ejection frequency, reproduction precision and regularity as well as, to a large extent, as far as costs and machine reliability; furthermore we point out that the type of used nozzle conditions also the choice of the typology of the used dyestuffs/inks.
Research and design costs for these machines are extremely high (dozens of million dollars), so that there are only 4-5 multinationals manufacturing them; their main market is paper printing (which has exigences not always compatible with fabric printing).

2.a) Thermal nozzle – Bubble-jet
A small quantity of duyestuff in aqueous solution is instantly heated up to 250-350°C in a small chamber. The steam bubble which is instantly created causes the ejection of an ink drop from the nozzle, while the successive sudden cooling originates a contraction of the ink, with consequent drop interruption. The obtainable ejection frequency is high enough (max. 30.000 drops/s).
The resolution levels are quite good and vary from 360x360 to 1440x1440 dpi (resolution used for textiles is 360 to 720 dpi).
This technology permits to produce plates with a great many nozzles at relatively low costs; on the other hand it requires the use of inks with particular characteristics, suitable to the high operating temperatures. Besides, nozzles can be subject to progressive and rather quick wear and tear due to the deposits (formed through dyestuff decomposition and/or salt precipitation) caused by the high temperatures attained in the steaming chamber, with consequent variation of drop size as well as of ejection and or blocking frequency. In view of all this, these nozzles are insufficiently reliable both owing to the chromatic variations due to altering and to the fact that, although in the printing heads with very high number of nozzles the production costs for the single nozzle are quite low, the improper working of a small part of these nozzles is sufficient to lead to the replacement of the whole head, with ensueing process interruption and additional costs.

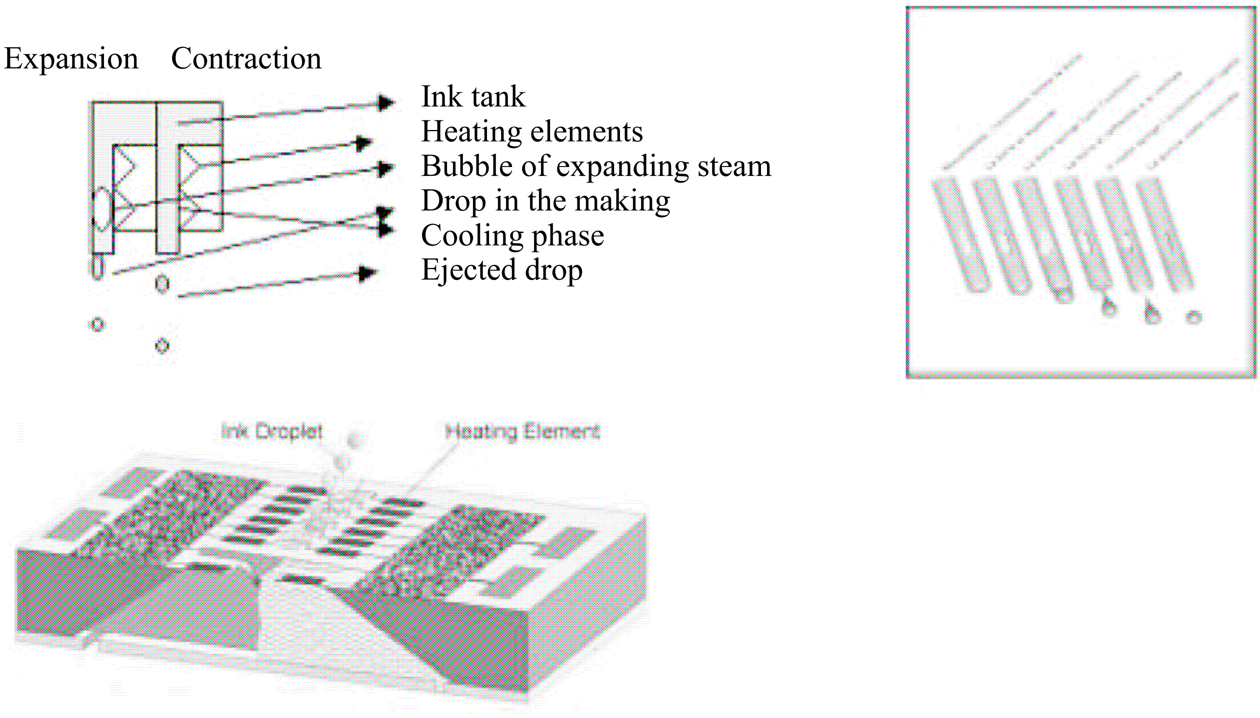


Fig. 132 Bubble-jet printing head

2.b) Piezoelectric nozzle

This nozzle causes the drop-wise ejection of the ink placed in a small chamber, through deformation of a crystal subjected to the action of an electric field.
This technology is more precise and reliable than previously described technology, owing both to the longer life of crystals in respect to heating elements and to the considerable reduction of reliability problems connected with fouling; moreover it permits the use of less sophisticated inks/dyes (which are therefore less expensive, even if accurately controlled to ensure a durably constant surface tension). At this moment it is not yet possible to produce plates (printing heads) with very high number of nozzles, and the single head is much more expensive than previous head types, but on the other hand the ejection frequency can attain very high levels (max. 100.000 drops/s).
The resolution values are quite high and vary from 360x360 to 2880x2880 dpi (from 360 to 720 dpi for textile applications).

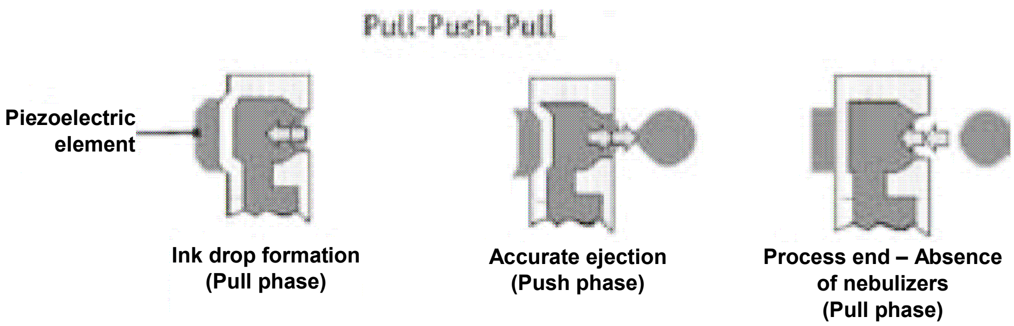


Fig. 133 Piezoelectric nozzle

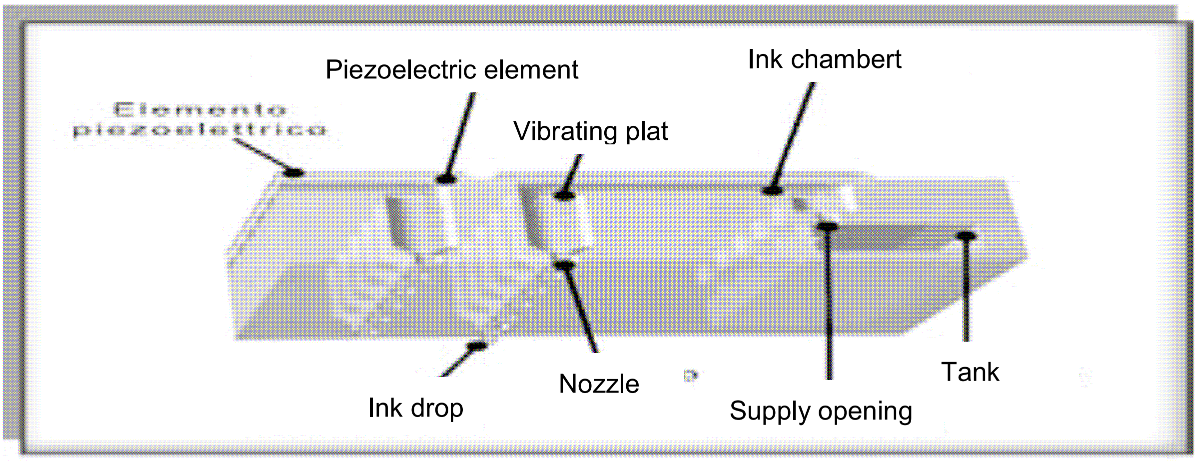


Fig. 134 Printing head with piezoelectric nozzles

3. Pattern resolution and size of used drop

A basic concept in the field of digital printing is pattern "resolution", a parameter which is expressed by the number of "dots" per sq.inch (dpi). The higher is the dpi value, the higher is the resolution. A higher resolution permits a better pattern definition, but in particular permits to better define the smallest details and the thinnest borders, avoiding the phenomenon of indentations.
Each dot can be filled in different ways:
3.a) FDS (Fixed Dot Size) digital modulation
3.b) VDS (Variable Dot Size) analogic modulation

3.a) With the FDS method, a dot is filled with a certain number of drops of same size. If a full tone is printed, the dot will be filled for instance with 9 drops, whereas to obtain the same tone but increasingly light-coloured, the same dot will be reproduced with an ever-decreasing number of drops (always of same size). The advantages of this method lie in its simple application due to constant drop size and to uniform drops penetration into the fabric both in case of light and dark colours (drops of same size penetrate uniformly).
The disadvantage lies in the variation of pattern definition, which will result good with dark colours and less good for light tones; the dotted effect due to the distance between each drop (e.g. 1 drop per dot, surrounded by a rather large white area) will become perceptible for the human eye, in particular on fabrics with smooth and even surface, and will create difficulties in the reproduction of gradual hues.3.b) With the VDS method, the tone is adjusted both through the number and the size of the drops. This permits a higher graduality in the tone variation and consequently a lower perception of the dotted effect in the light tones (for instance, 9 small drops per dot instead of one or two big drops) and more graduality in the hues; on the other hand, a different penetration level from light to dark tones will result, owing to the different drop size.
Both the present technology of thermic and the technology of piezoelectric nozzles permit the modulation of drop size (the perfect control depends on ejection frequency: at an excessive frequency, the control results precarious). In this case the piezoelectric nozzles, besides having the advantage of a proper ejection frequency, enable a correct and constant modulation, whereas the thermic nozzles modify drop size in the course of time owing to formation of encrustations.

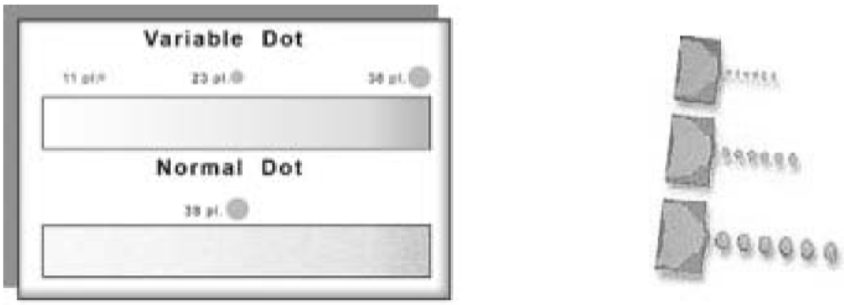


Fig. 135 Drop modulation

The Process printing technique

This system reproduces design patterns by means of a technique similar to digital printing on paper (dietering): by using four colours (four-colour printing with 4 printing heads) or seven colours (seven-colour printing with 7 printing heads) and by mixing and/or spreading on the fabric dye drops of different colours (this step is controlled completely by special software), different shades can be accurately reproduced in terms of colour, brilliancy, depth of shade.
In fact the ink drops of the various dyestuffs which are needed for the reproduction of the desired colour will be positioned on the fabric in a quantity (drops number per dot) such as to permit to our eye, whose definition capacity is not sufficient to single out and evaluate the colour of each drop, to calculate an average value within the process of additive synthesis.

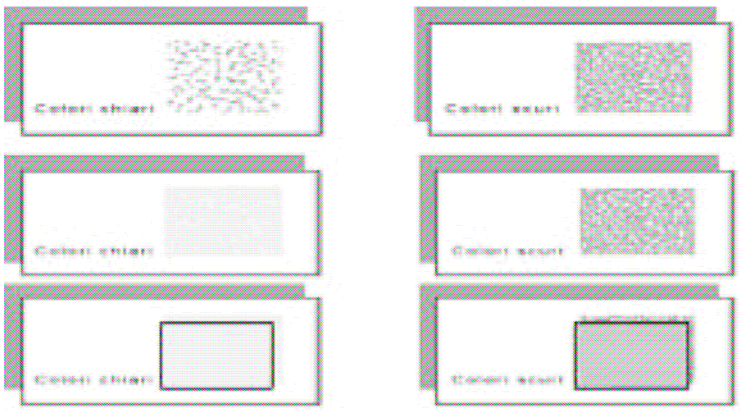
The Process printing method offers a wide range of advantages:
- automatic control by the software of colour reproduction (colour space is limited in respect to traditional printing, but is sufficient for basic necessities)
- elimination of the necessity of a colour kitchen and thus of all problems implied by its management
- possibility to print immediately the digitalized patterns also without any pattern manipulation, contrarily to traditional printing with transparency separation or in four-colour reproduction (photographic reproduction) with an endless number of colours and hues.
- Possibility to produce on the fabric photographic prints of excellent quality which are not obtainable with traditional printing

It entails however also several problems:
- photographic prints are not reproducible with traditional printing and variants are not obtainable neither with digital printing (or otherwise with great difficulty and in a very limited number)
- difficulty in obtaining light and flat shades through the use of only one ink; it becomes even more difficult if the light shade is the result of the combination of 2 or 3 different inks
- Problems of dotted effects and/or of moireing in the hues
- Difficult colour penetration for light tones
- Limited colour space with respect to traditional printing and also to Spot printing (60-85% of the colours, depending on number and tones of used inks)

We wish to point out that the manufacturers of these technologies are focusing their efforts on the development of nozzles which permit prints with increasingly high definitions (1200-2000 dots per inch), with smaller and smaller droplets: this suits paper printing, but not textile printing, as so high definitions are useless (720 dpi are already the optimum for textile prints on silk substrates) and imply reliability problems (nozzles with extremely small holes which get clogged up, insufficient penetration, etc.).

Spot printing technique

The colours to be reproduced are prepared by mixing master batches (similarly to traditional printing) and suitably diluted (a special colour kitchen must be set up). Therefore it would be necessary to use as many inks as the colours of the pattern and as many printing heads as the colours. This technique allows the printing of the fabric with the same number (maximum number) of ink drops per surface unit, by eliminating dotting and moireing problems, unevenness and enhancing the penetration in patterns with grounds in pastel colours. Obviously patterns with a huge number of colours cannot be reproduced (each colour must have its corresponding printing head and an excessive number of printing heads would make the printer less reliable). This makes the printing process very difficult and requires using a special colour kitchen, and washing the printing heads at every pattern varying, thus causing time losses and serious problems for the nozzles, particularly for piezoelectric nozzles (which have drop ejecting holes with diameters as fine as 10-12 micron).
Not to be neglected is the fact that ink mixing implies a wide range of precautions to prevent the presence of solid particles (dusts) and/or air which would jeopardize print quality and productivity.



FDS Process

VDS Process

Spot Process

Fig.136 Printing results with the various technologies

It is also possible to properly combine the two technologies (Process and Spot) to attain the best results.

Printing speed and quality

As to ink-jet printing, the quality result is inversely proportional to printing speed and depends on various factors.

Operating cycle of the printing head

As mentioned before, there are two different printing technologies, namely the **piezoelectric** and the **thermic** technologies; these technologies are characterized by different printing heads, but both processes presents some speed limits in terms of ink drop formation and of its subsequent delivery on the substrate, as well as in terms of time needed to activate a new operating cycle:
- in the case of thermic nozzles, these limits are of physical nature and are due to the so-called "thermic transient state", that is the period during which the resistor inside the nozzle cools down, new ink enters and a new ink heating phase is activated.
- in the case of the piezoelectric process, the limits are of electromechanical nature, with problems of vibrations which are sparked off at the attainment of the frequency limits to which the piezoelectric device is submitted in the course of time.

- In any case, by limiting the number of processes for the formation of ink drops in the unit of time, the printing speed is automatically limited.
  All manufacturers have developed, to increase printing speed, printing heads equipped with a high number of nozzles, with ensuing deposition of a bigger quantity of ink in the unit of time and therefore higher printing speed.
- The various plotter manufacturers assemble the printing plates according to the speeds to be attained: the higher is the nozzles number per printing head, the higher is the speed; the more the printing heads per plate, the higher is the printing speed (with same number of colours).

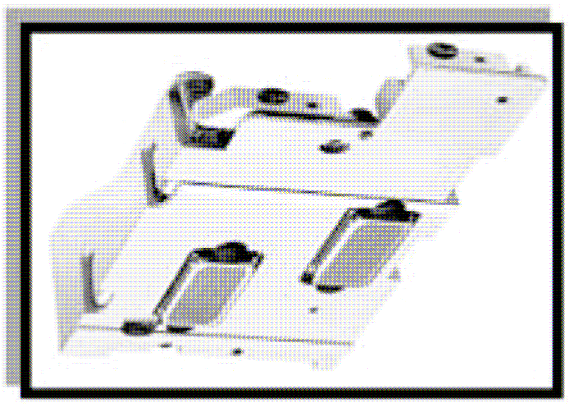


Fig. 137 2 printing heads with 2 series of 180 nozzles

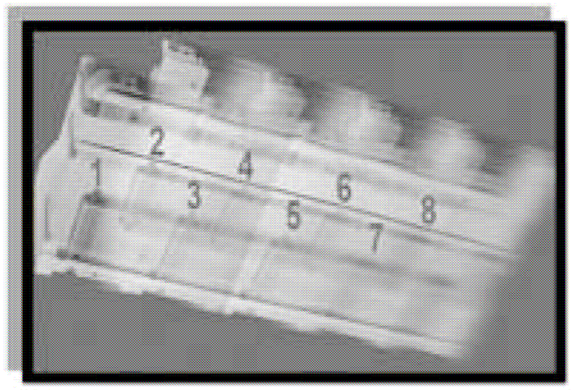


Fig. 138 Plate with 8 printing heads positioned on two rows

Variable drop
The use of large-sized drops requires, for filling-in a certain printed area, a lower number of drops than with the use of small-sized drops; therefore the use of large-sized drops speeds up printing.
We should however keep in mind that drop size is also related to the quality aspect: the capacity of the printing head to create drops of different sizes, from the smallest drops of about 2-3 pl (1 picoliter = 10-12 l) to the largest ones of 35-40 pl permits to obtain light not dotted printing grounds and gradual shades. A nozzle which permits to regulate drop size ensures the possibility of adjusting printing speed according to what we are printing; the droplets guarantee an optimum resolution and image definition, while the larger drops speed up the filling-in of the deeper and even coloured areas in absence of shades.
Extremely important is the combination nozzle/ink, as the projected drop must reach the textile material in a spheric, not ovoidal shape and must not form satellite drops in order to avoid reducing definition and producing unclear edges in the pattern.

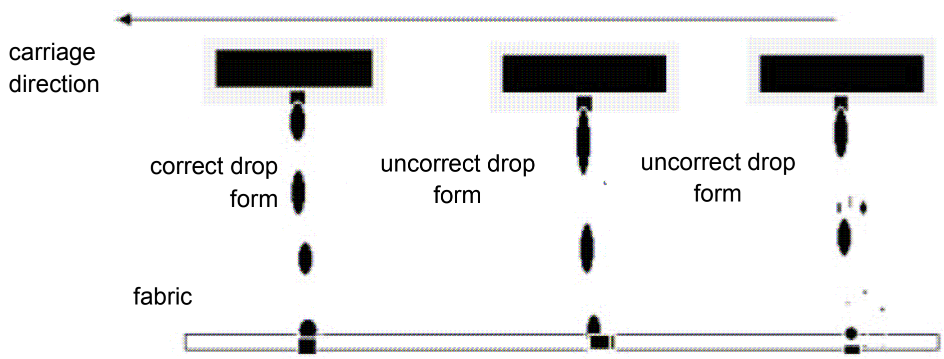


Fig. 139 Examples of possible defects in drop formation

Synchronism in the printing head/fabric movements

During ink-jet printing, the resulting quality is closely connected to the control and synchronism of three movements:

The movement of the drop from the nozzle onto the fabric (z axis)
The movement of the nozzle mounted on the carriage along fabric width (y axis)
The advance path of the fabric (vertical step, x axis)

The target is to obtain high precision in the synchronism of the movements, therefore in the positioning of the printing head and consequently of the drop on the fabric, which is a very important aspect if good quality prints have to be produced.
Increasing the printing speed prejudices the precision in the movements synchronism as well as production quality.

Printing drivers

The drivers and the software itself control the printing process. The software governs all printing phases, from the preparation of the image to be printed to the movement of the printing head, to drop formation, to colour management, and so on. The control does not depend always on the printer: often several parameters are controlled by the integrated CAD (software) system, while other parameters are controlled by the printer.

Printing speed, substrate and regulations

An increase in the printing definition (dots/inch^2) forces the printing head to fill-in with the ejected drops a higher number of dots per passage: as ejection speed is limited, a higher dot number per area unit requires a higher number of drops; to spray a higher number of drops, a longer time is necessary (however we shall get dots positioned at closer range, therefore more precision, deeper tones, less thin areas and higher penetration).
In general the plotters carry out printing through several passages on the horizontal Y axis of the printing heads, which are coordinated with the advance movement of the substrate on the X axis.
An adjustable parameter is the distance of the printing heads from the fabric. This parameter has to be adjusted according to fabric thickness, keeping in mind that the printing heads must not touch the fabric (they would get soiled and damaged), but that the nearer they are to the fabric, the better will be the printing results (Fig. 140). On the basis of the selected print, of the desired printing speed, of the pattern typology to be produced and on the required quality, it is possible to select the assigned "steps" (Fig. 142) for monodirectional printing (slow and of good quality) and bi-directional printing (fast and of low quality) (Fig. 141). The combination between printing resolution, steps and mono- or bidirectional printing permits to obtain a more or less defined and quick print.

Fig. 140
Height adjustment of printing head according to the substrate

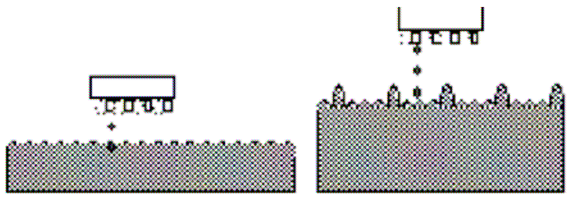
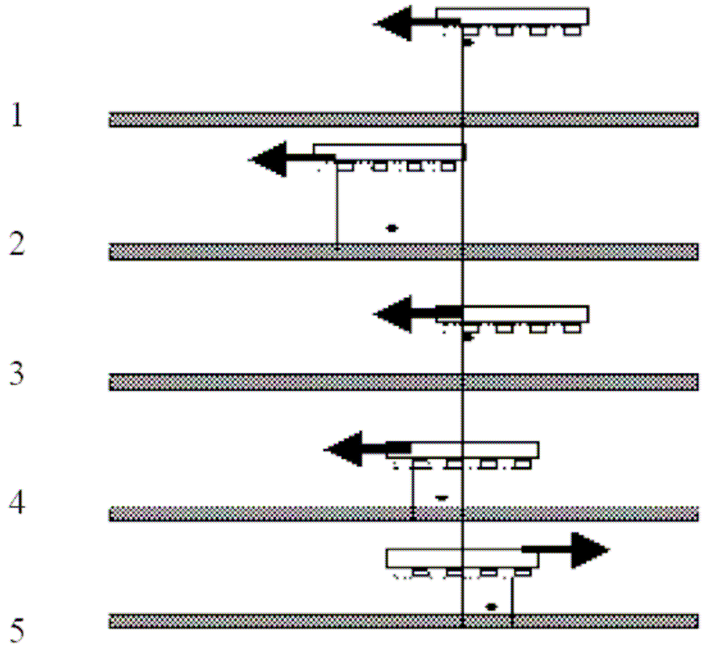
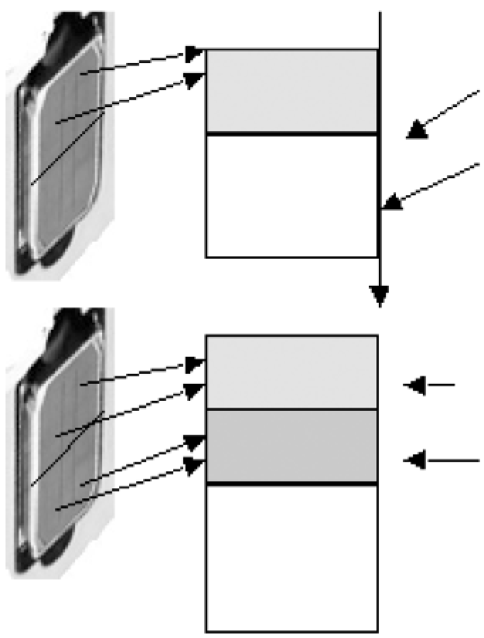


Fig. 141 Deviation of the drop deposition point on the fabric depending on the distance printing head/fabric with unidirectional printing (Fig. 1-2 and Fig. 2-4)

Deviation of the drop deposition point on the fabric with bi-directional printing (Fig. 3-4 and 3-5)



An increase in the steps number brings about a different managing method of the printing nozzles: should all the 180 nozzles of each head row print at the same time a pattern strip, then the strip would be printed in one passage only (e.g. a 4 cm long strip of a complete pattern).
If we carry out a two-step printing, the rows of 180 nozzles will be divided in two parts and at the first passage the first 90 nozzles will print a 2 cm long pattern strip; when the fabric has advanced 2 cm with the subsequent passage, the first 90 nozzles print a new pattern strip of 2 cm length and the second 90 nozzles print a second time the strip previously printed by the first 90 nozzles.



Fabric advance
1st step: printing by 50% of the nozzles (e.g. 90 nozzles)

the fabric advances (90 nozzles distance)

The first group of nozzles continues to print its 50% of the colour which will be completed with the subsequent step

2nd step: printing by the remaining 50% of the nozzles which complete the pattern (colour)

Fig. 142 Different results depending on the assigned steps

Obviously, if the number of steps is 4, a fabric advance corresponding to the distance of 180 nozzes will be completed in 4 subsequent passages of the printing head, each 1 cm long, therefore in a twice longer time.
A higher steps number entails therefore a slower printing, but permits to compensate managing errors of the nozzles due to some blocked nozzles or to not perfect synchronism of the movements fabric/printing heads, besides permitting to obtain fuller tones.

It is evident, that the desired quality will be strictly related to the pattern to be produced, to the substrate type and to the required quality and will be obtained by regulating the mentioned parameters.

Examples of possible modalities:
360x360 dpi 2/4/8 steps
360x540 dpi 3/6/12 steps
360x720 dpi 2/4/8 steps
720x720 dpi 4/8/16 steps

Fig. 143 Example of a 360x720 dpi 4 step-print

The causes of the imperfect fabric advance during printing are manifold and, when this occurs, can originate striped effects, the so-called **"banding".**
This fault is essentially due to the defective synchronization of the motion of the printing head carriage on the Y axis with the fabric advancing along the X axis.
Thanks to the controlled drive for the fabric advance, the defect becomes more evident with increasing printing speed, in particular in the case of fabrics which are deformable under stress (lightweight fabrics as organza, jersey knits, stretch fabrics). If we use machines provided with this fabric advance system, the optimum printing speed to avoid the banding defect is 1,5-3 m^2/h.

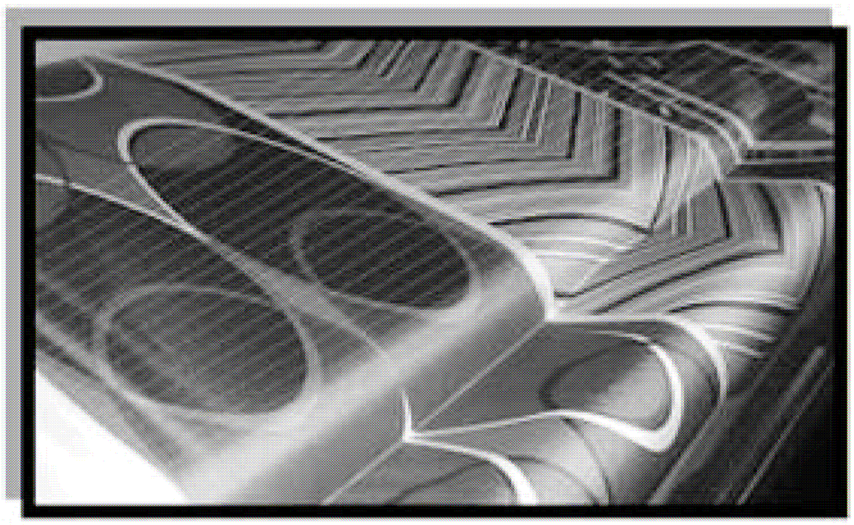


Fig. 144 Example of banding defect

If we use fabric transport systems with conveyor belt and fabric advance without tension, the problem connected with fabric elasticity is completely overcome.

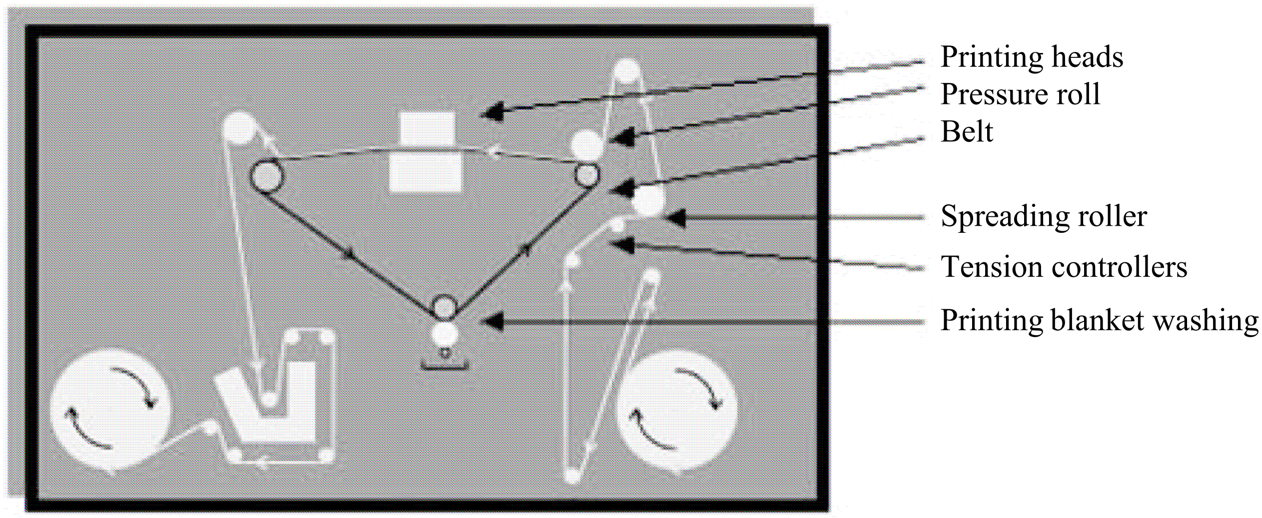
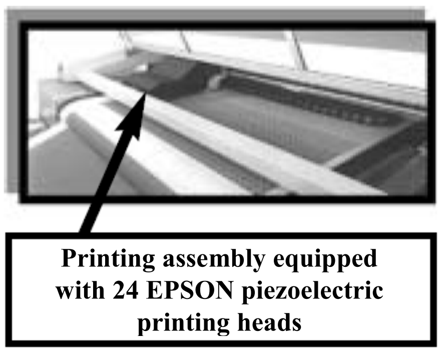


Fig.145 Scheme of ink-jet printing with belt-operated fabric transport

The fabric advance (in case of machines not equipped with resined printing blanketing) is generally regulated through a test which must be carried out at each new fabric loading.

Illustrations and features of ink-jet printers on the market

Production/sampling machine



- 8 colours
- 24 printing heads
- Definition: min. 360 dpi – av. 450/540/630 dpi - max. 720 dpi
- Max. speed 120 sqm./h (cruising speed 30 sqm/h)
- Equipped with adhesive printing blanket
- Washing system for the printing blanket
- Infrared drying system for the printed fabric
- Winding system of the fabric on beam
- Height adjustment of printing heads

The machine can operate with monodirectional or bidirectional printing system, with drops of various sizes: big, medium, small or variable size. Inks are delivered by special sealed sacs.
The operation at standard conditions permits a considerable ink saving (in case of lightweight fabrics), while at extra conditions permits a good ink penetration into heavy-weight substrates.

Fig. 146

Production/sampling machine

Fig. 147

- 6 colours
- 42 printing heads
- Definition:

Fixed definition: 600x600 dpi

- max. speed: 160 m^2/h (1600 mm width)
- max. speed: 190 m^2/h (2200 mm width)
- Drying system of the loft-printed (or cured) fabric with take-up on beam

- Equipped with adhesive blanket
- Blanket washing system
- Adjustable width of printing heads
- Max. fabric width:

1600 mm

2200 mm

The machine operates with bi-directional 1-, 2-, 4-step printing.

Drop size is fixed.

The inks are fed by cans and carried into an internal chamber at fixed level and pressure conditions, after being filtered and degassed. A safety system informs if the ink level in the cans is low (replacement needed), while a subsequent safety device interrupts the printing operation if the working conditions (ink level, pressure) in the internal tank are going to be modified.

TEXTILE FINISHING

The chemical structure of natural, artificial or synthetic fibres determines some of the properties that are naturally present also in finished products. Some fibres (such as linen, hemp, silk, nylon, polyester) are stronger than others (wool, viscose, acrylic) according to more or less controlled distribution of macromolecules in the polymer mass, structure stiffness and any possible inter and molecular interaction between the chains; other fibres tend to distort when stretched (cotton, viscose), and others recover their original shape after being distorted (wool); some others easily burn (cellulosic fibres), burn slowly and self-extinguish (wool, silk) or burn and melt (man-made fibres).
These and other characteristics make up positive and negative properties of a textile material, which must be accurately considered in view of their final application. The textile product final application will be considered from many points of view: wearability, hand, mechanical resistance, wettability, washability, deformability, fire-proof ability and many others.
The word “textile finishing” defines a series of processing operations applied to grey fabrics to enhance their appearance and hand, properties and possible applications. The term “finishing” includes all the treatments applied to grey fabrics such as scouring, bleaching, dyeing or printing while we will use the term “permanent finishing” with reference to all the mechanical or chemical finishing operations carried out on fabrics already bleached, dyed or printed to further enhance their properties and possibly add some new ones.
The terms “finishing” and “permanent finishing” are therefore similar and both play a fundamental role for the commercial success of textiles, strictly depending on market requirements that are becoming increasingly stringent and unpredictable and permit very short response times.
Depending upon the type of textile substrate to be treated (staple, yarn or fabric) finishing processes are carried out using different means:

Mechanical means:	involving the application of physical principles such as friction, temperature, pressure, tension and many others.
Chemical means	involving the application of synthesis or natural chemical products, which bind themselves to the fibres more or less permanently
Combined mechanical and chemical means	involving the application of both chemical and mechanical processes

The main purposes of permanent finishing processes are the following:
- Develop the "product finish" in all its fundamental elements such as hand and appearance;
- Give the finished fabric some properties that grant an optimum behaviour during the making-up and all through the life of the textile.

The parameters influencing the choice of the most suitable finishing process are the following:

- Fibre nature of the fabric to be subjected to permanent finishing treatments
- Final application of the fabric to be subjected to permanent finishing treatments

Mechanical finishing treatments

Mechanical finishing processes can be referred to as the processes generally carried out on open-width dry fabrics, with or without heat application, which give the fabric good dimensional stability (shrink proof and shape retention) and modify the "hand" of the textile product by altering its structure or at least its surface structure.

Dry finishing treatments

Calendering: a lustrous, dense and compact appearance can be obtained by means of friction, pressure and heat.

Glazing: this calendering operation is carried out using special calenders and exploiting the combined actions of heat, friction and polishing agents.

Embossing: this particular type of calendering process allows engraving a simple pattern on the fabric.

Sueding: through this process, the fabric gets a much softer hand and an improved insulating effect thanks to the fibre end being pulled out of the fabric surface. This process is carried out by means of a roller coated with abrasive material.

Raising: the fibre end pulled out of the fabric surface imparts a thermoinsulating effect. This process is carried out by means of hook-needles running in different directions on the fabric.

Shearing: the fibre ends on the fabric surface are cut by using special cutting tools.

Singeing: the fibre ends pulled out of the fabric surface are burnt by means of a flame (see preliminary treatments).

Wet finishing treatments

Wet calendering: this process is quite similar to the dry one. The only difference is the use of steam.

Fulling: the structure, bulk and shrinkage of wool are modified by applying heat combined with friction and compression.

Sanforising: the fabric is given dimensional stability by applying mechanic forces and steam.

Decating: the lustrous appearance of the textile material is eliminated, the surface is smoothed and the fabric is given dimensional stability through the action of dry or overheated saturated steam.

Calendering

This non-permanent mechanical finishing treatment is applied to fabrics made of cellulose, protein and synthetic fibres, by means of a calender. This machine generally includes one or a series of couples of rollers pressed one against the other with adjustable pressure and identical or similar tip speeds. The cloth passes through one or more couples of rollers, which exert a smoothing and a pressing action. Some rollers are stiff while some others are made of softer material. Stiff rollers are generally made of steel or hardened cast iron and the surface can be chrome-plated, nickel-plated or made of stainless steel and can be subjected to treatments that give:
a dull appearance similar to the result of abrasive blasting;
a cross-stripe engraving to improve the fabric resistance to sliding;
a very thin diagonal stripe patterning with silk-sheen appearance;
a patterned engraving with embossed effects.

The fabric passing through the rollers of the calender is subjected to a very uniform pressure all along its width; if the rollers rotate at a different speed, a vigorous friction effect is generated.
Steel rollers may be equipped in such a way to be heated from the inside by means of steam, circulating fluids or electrical power. They are supported by a vertical central frame made of steel, having the same size of rigid rollers, while the surface is coated with softer material like cotton (to stand high temperatures), wool paper (to enhance the glaze finish), or jute, wool or plastic material such as polyamide.
The rollers coated with paper/wool, containing 45-50% of wool, feature good elasticity and excellent resistance to wear and are suitable for a wide variety of applications; they can also be used in embossing calendering units.
Rollers made of paper/cotton, are used almost in friction calenders and for treating "hard" fibres, thanks to their high resistance capacity. Cotton rollers, featuring higher elasticity than the paper ones, are mainly used for cotton and blends finishing and for a final full hand effect.
The life of cotton-polyester or polyamide rollers is considerably longer; in fact they are very resistant and cannot be easily etched by the passage of creases, knots or sewing. Thanks to their improved hardness, they produce on the fabric a particularly lustrous appearance and allow higher operating speeds.
The effects on the cloth can be set permanently by using thermoplastic fibres or by applying suitable (thermosetting resin or reactive-based) finishing products.
The use of different types of calenders gives different effects such as:

Sheen appearance:	it can be obtained by smoothing the cloth surface, which ensures a better reflection of light.
Better coverage:	it is due to the compression of the cloth, which generates a flattening of each single yarn.
Softer hand:	it is obtained thanks to a slight ironing effect, which produces a smoother and softer cloth surface.
Surface patterns:	they can be obtained by means of special effects ("embossing" for example) for decorative purposes or to modify the surface smoothness.
Yarn swelling and rounding effect:	these give a modest glaze finishing to the fabric, a surface smoothness and above all a fuller and softer hand.

The main types of calendering units are:

Two-roller calenders: they are made up of a smooth roller coupled with a metallic one, which can be heated. The tip speeds of the two cylinders can be different: this system architecture produces a certain friction, which gives a high glaze effect to the fabric. The lustrous effect depends on the different rotation speed, pressure and temperature.

Three-roller calenders: the most common combinations are the following:

- elastic-steel-elastic rollers: this structure allows a better lustrous effect and gives the cloth a fuller handle.
- steel-elastic-elastic rollers: this combination allows different effects. If the cloth passes through the two elastic rollers, it gets a matt appearance and a fuller hand.

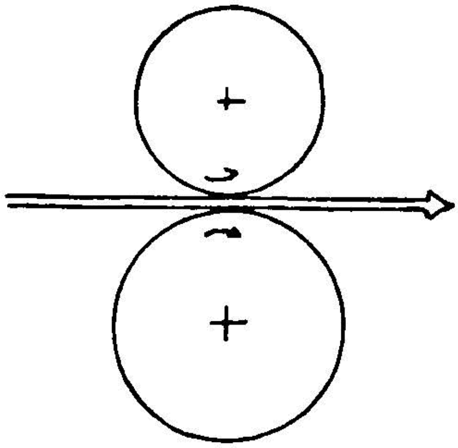


Fig. 148 Two-roller calender

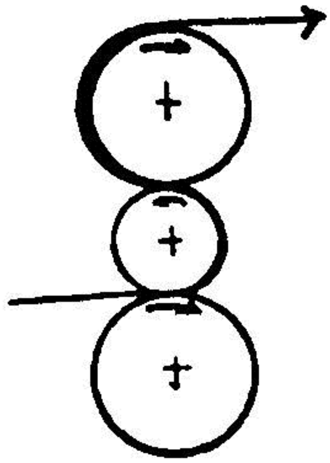


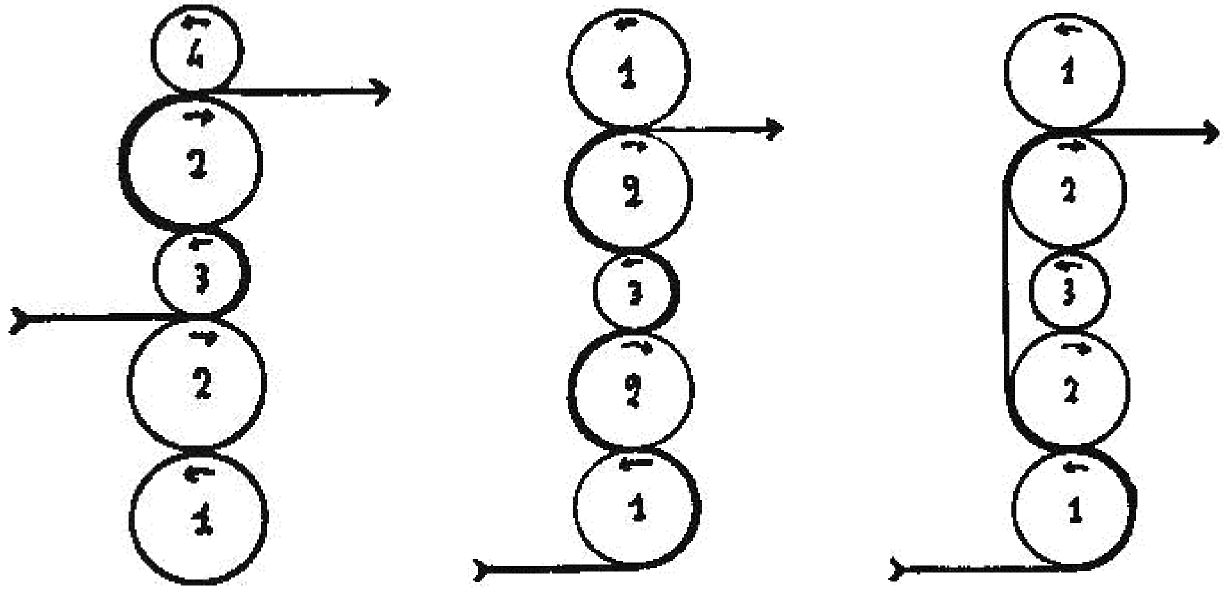
Fig. 149 Three-roller calender

Universal calenders: these calenders, equipped with 3-5-7 or even more rollers, are referred to as universal calenders. They can give the fabric different effects; some of them are detailed below:

roll effect: flattened fabric, high coverage ratio, soft hand and moderate glaze;
matt effect: high coverage ratio, soft hand and matt effect;
lustrous effect: this effect originates from friction created during the passage between an elastic and a steel roller.

Mercerizing-like calenders: by means of a high pressure (300-400 Kg/cm^2) and temperature, applied during the passage of the cotton cloth (which is still wet when passing through the rollers), a highly glazy effect can be created, similar to the one obtained with the mercerizing process.

Silk calenders (silky effect): the silky effect is obtained by feeding the cloth between a steel roller engraved with very thin diagonal stripes and a paper, cotton or rubber roller.
Satin or poplin fabrics are generally treated with this type of calender. The engraved cylinder can be heated to enhance the modification of the fabric surface.



Silky effect	Roll effect	matt effect

Fig. 150 Calenders for different effects

Mangling calenders: they exert a strong pressure on a cloth wound in rolls. The effect of such a pressure between the yarns leads to an accentuated rounding of the yarn with a subsequent increase of the fabric density and a highly lustrous finish. Mangling calendering can be carried out by feeding the wound cloth between two or three cylinders, which exert a powerful pressure by an alternating rolling-off and rewinding motion. This treatment is particularly valuable for pure linen or blended linen fabrics, which can be subjected to pressures up to 40 t.

Chaising calenders: the arrangement of rollers in chaising calenders allows the fabric to be wound several times inside the calender in a number of layers ranging from 5 to 13. In this way the pressure is not exerted directly by the flat surfaces of the cylinders, but by the fabric itself. The warp and weft yarns carry out a progressive rounding action; the result is a precious lustrous effect, a more bulky, full and compact hand, similar to the one obtained with mangling calenders.

Wedge calenders: these calenders are used for finishing wool fabrics. They are made up of a single roller on which the fabric is pressed by a metal wedge. The metal wedge envelops almost half of the whole circumference of the roller. This special calendering process gives a good lustrous effect, thanks to friction and to a moderate pressure exerted on the fabric.

Moiré effect: this effect occurs when a series of yarns with uncertain parallelism exerts pression on another series of yarns which forms with it a slight and variable angle. The moiré effect can be preferably produced on silk, rayon, wool and linen fabrics and is due to the different light reflection on the weft yarns, which in some points of their path had been compressed or flattened . A good moiré effect can be obtained on fabrics with coarse yarns in weft and fine yarns in warp.

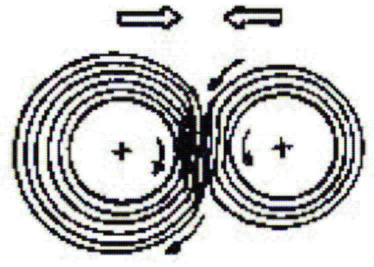


Fig. 151 Wind on-wind off mangle

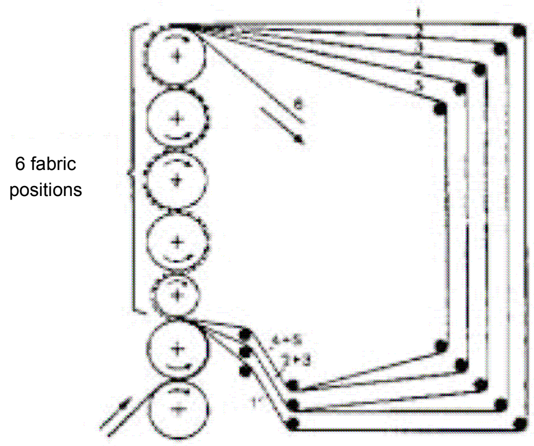


Fig. 152 Chaising calender

Wool fabric calendering

A process which gained ground since some years in the wool industry is calendering, which has essentially the purpose of reducing fabric thickness in the same way as the traditional calendering process, but brings about further advantages, like the improvement of the fabric handle and of the mechanical parameters of garment making-up (the so-called FAST or KES measurements). Moreover it eliminates some disadvantages connected with excessive fabric lengthening.

The process consists of a first phase of fabric pre-moistening and of a subsequent passage which brings the fabric into contact with one or more steam-heated rolls (temp. 120-150°C), partially wrapped by a waterproof technical cloth.

The cloth is subjected to high tension, so that during the passage of the fabric a heavy mechanical pressure arises on the part of the cloth which is in direct contact with the heated roll(s). It has to be noted, that the humidity contained in the fabric (which has been previously delivered by proper dampening/nebulizing units) is converted into steam, as a consequence of its contact with the hot surface of the effect roll(s). This process is carried out, with different settings and modalities, both before and after decatizing in autoclave.

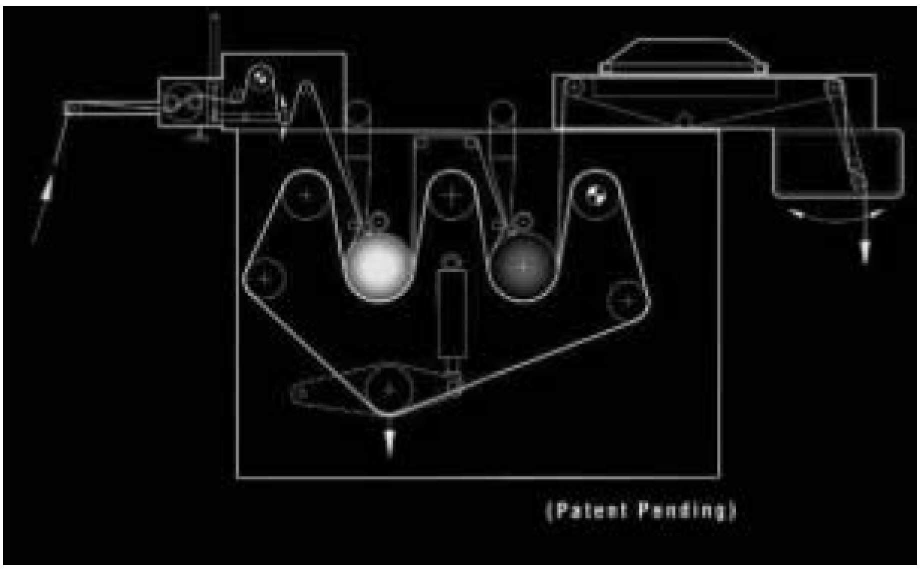


Fig. 153 Scheme of pressing equipment for wool fabrics

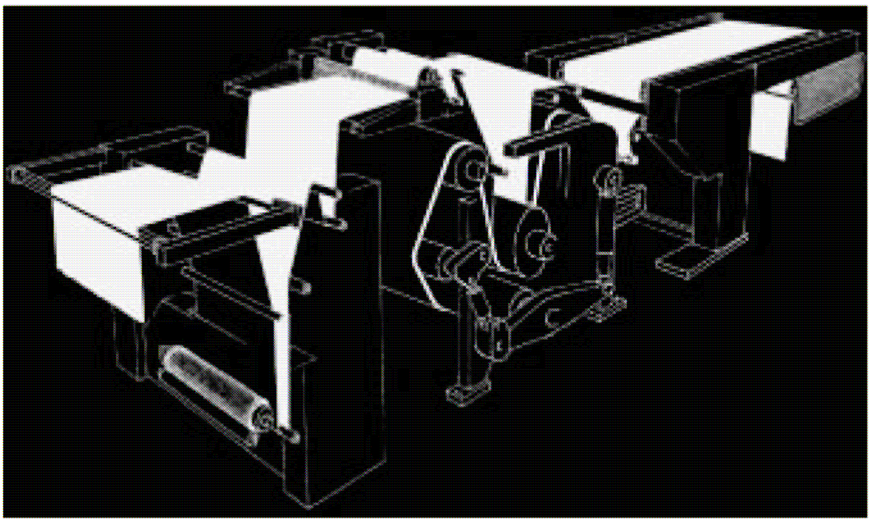


Fig. 154 Scheme of pressing equipment for wool fabrics

Embossing

Embossing is a particular calendering process through which a simple pattern can be engraved on the cloth.
The embossing machine is made up of a heated and embossed roller made of steel, which is pressed against another roller coated with paper or cotton, its circumference being exactly a whole multiple of the metal roller. A gear system drives the harmonised motion of the rollers, preventing them from sliding and granting a sharp engraving of the patterned design. After being engraved, the pattern can be stabilised by means of an appropriate high-temperature treatment or by applying suitable starchy substances.

Sueding

This operation is often carried out before the raising process to reduce the friction between the fibres composing the cloth and consequently to facilitate the extraction of the pile.
The sueding process is carried out on both sides of the fabric and modifies the appearance and the final hand of the cloth, giving a soft and smooth sensation similar to peach skin.The sueding machine is made up of some rotating rollers coated with abrasive paper, which emerise the cloth and produce a more or less marked effect depending upon the pressure exerted on the fabric by the abrasive rollers. The abrasive paper used can vary according to the desired sueding degree and must be replaced after a given number of operating hours, or when it does not properly carry out suitably the sueding function. In some cases, it is possible to use also metal rollers with the surface coated with uneven and rough grains or pumice rollers performing an excellent sueding action on both dry or wet fabrics. For a very superficial sueding, the natural abrasive power of pumice can be applied with successful results.
Grey fabrics as well as dyed ones can be subjected to the sueding process; the cloth to be emerised must be completely free from any finishing resin or adhesive substance remaining on the fabric surface after desizing. The sueding process reduces mechanical and dynamometric resistance of the fabric, thus making it more subject to tearing and seaming.
The fabric can run at different speeds inside the sueding unit; a constant pressure is kept thanks to two balancing arms positioned at the entry and at the exit of the unit. The pieces of cloth must be sewn with abrasion-resistant material such as polyester or nylon. The gears must be suitably cleaned with compressed air jets since the presence of pile residues could clog the ball bearings or drop again on the fabric surface, thus creating some problems with dyeing machines filters. The sueding

process, which can affect the fabric with a very wide range of effects, can give some problem when applied to knitted tubular goods but it is widely used on woven fabrics with different weights and weaves (its application ranges from coarse jeans cloth to light and delicate silk or microfibre, coated fabrics and leather imitations).

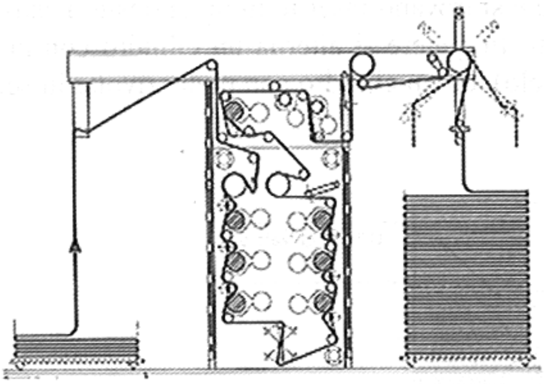


Fig. 155 6-cylinder sueding machine

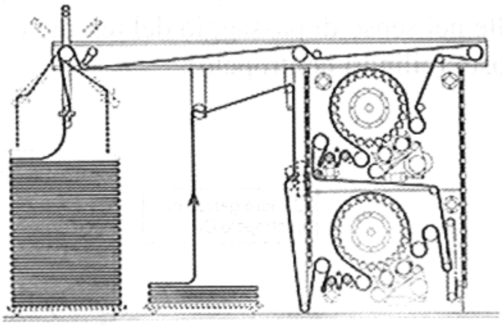


Fig. 156 24-cylinder sueding machine

The sueding unit is equipped with 6 rollers performing the sueding action on the face of the fabric and 1 roller performing its action of the back of the fabric; an advantage of this system is the possibility to use sueding cloths with different grains on each single roller. Thanks to three dandy rollers, the sueding action can be automatically adjusted during the fabric processing thus allowing the sueding process to be carried out also on knitted goods.

The 24-roller sueding unit assembled on 2 rotating drums features some advantages if compared to traditional machines equipped with 4-6-8 rollers:

- the combined action of several rotating rollers and the beating effect grant a smooth sueding, and a much softer hand than any other machine; no differences are generated between the centre and the selvedge; no stripes are formed on the fabric;
- the wide contact surface allows very high operating rates. The large number of moving rollers performs a gentle action on each sueding roller, thus granting the maximum sueding smoothness. Furthermore the life of the abrasive cloth is much longer than on conventional machines. In fact, 100,000–150,000 meters of synthetic fabric and up to 200,000–250,000 meters of 100% cotton fabric can be processed in standard processing conditions before replacing the abrasive;
- sueding units can also be transformed into raising (napping) units by assembling a special conversion kit.

All sueding machines are equipped with a brushing unit assembled at the exit to reduce the powder resulting from the sueding process.

Raising (Napping)

The raising process is a very old technique, known also by the ancient Romans (as illustrated in some paintings found in Pompeii). This operation is particularly suitable for wool and cotton fabrics; it gives a fuzzy surface by abrading the cloth and pulling the fibre ends onto the surface. During these last years, this process has also been applied on polyester/viscose blends and acrylic fabrics.
By means of this process, a hairy surface can be given to both face and back of the cloth providing several modifications of the fabric appearance, softer and fuller hand. This enhances the resistance of the textile material to atmospheric agents, by improving thermal insulation and warmth provided by the insulating air cells in the nap. The fuzzy surface is created by pulling the fibre ends out of the yarns by means of metal needles provided with hooks shelled into the rollers that scrape the fabric surface. The ends of the needles protruding from the rollers are 45°-bent hooks; their thickness and length can vary and they are fitted in a special rubber belt spiral-wound on the raising rollers. These rollers are generally alternated with a roller with hooks directed toward the fabric feed direction (pile roller), and a roller with the hooks fitted in the opposite direction (counterpile roller).

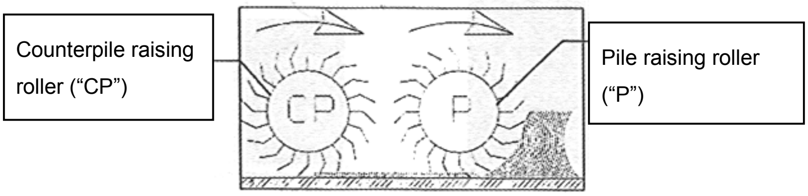


Fig. 157 Scheme of the raising rollers

The machine also includes some rotating brushes, which suction-clean the tips in pile and counterpile directions. Actually the trend goes towards a ratio of raising rollers/pile rollers equal to 1/3. The two series of rollers have independent motion and can rotate with different speed and direction, thus carrying out different effects.

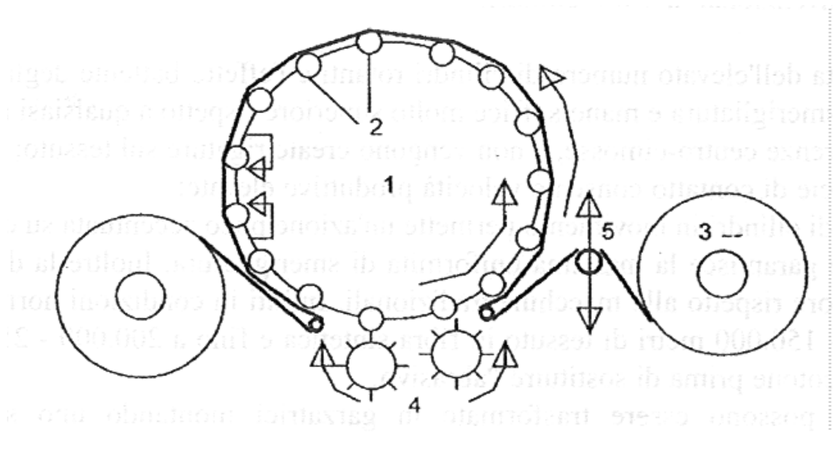


Fig. 158 Raising machine:1: drum; 2: rollers equipped with hooks;
3: fabric;4: nib cleaning brushes;5: fabric tension adjustment

The action of these systems is rather powerful and the results depend on the effects and on the type of fabric to be processed .
The raising effect can be obtained by adjusting the fabric tension (5) or by adjusting the speed and the roller rotation direction (2).

Once a certain limit has been exceeded, the excessive mechanical stress could damage the fabric: it is therefore preferable, when carrying out a powerful raising, to pass the fabric through the raising machine many times (wet fabric when processing wool fabrics, dry fabric with cotton fabrics) and treat the fabrics in advance with softening-lubricating agents.
The pile extraction is easier when carried out on single fibres: it is therefore suitable to reduce the friction between the fibres by wetting the material or, in case of cellulose fibres, by previously steaming the fabric.
For the same reasons, it is better to use yarns which are only slightly twisted.
The same machine allows different options of independent motions:

- fabric moving between entry and exit
- motion of main cylinder
- motion of raising rollers

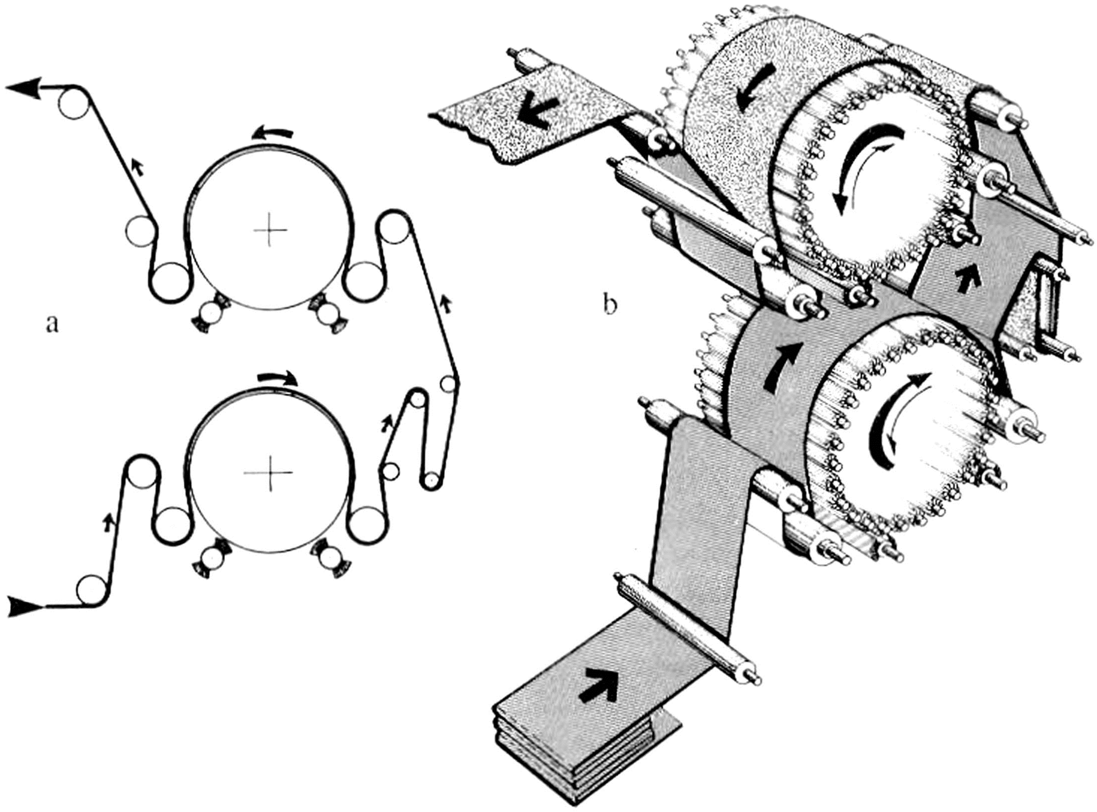


Fig. 159 Raising of fabric right and back side : a) scheme; b) view

The raising intensity can be adjusted by suitably combining the above mentioned independent motions, the tension of the textile material, the number of “pilewise” (P) or “counterpile” (CP) raising rollers and their relative speed.
It is possible to obtain- , through pile combing, "semi-felting" effects with fibres pulled out and re-entered in the fabric, or a “complete felting“ effect.

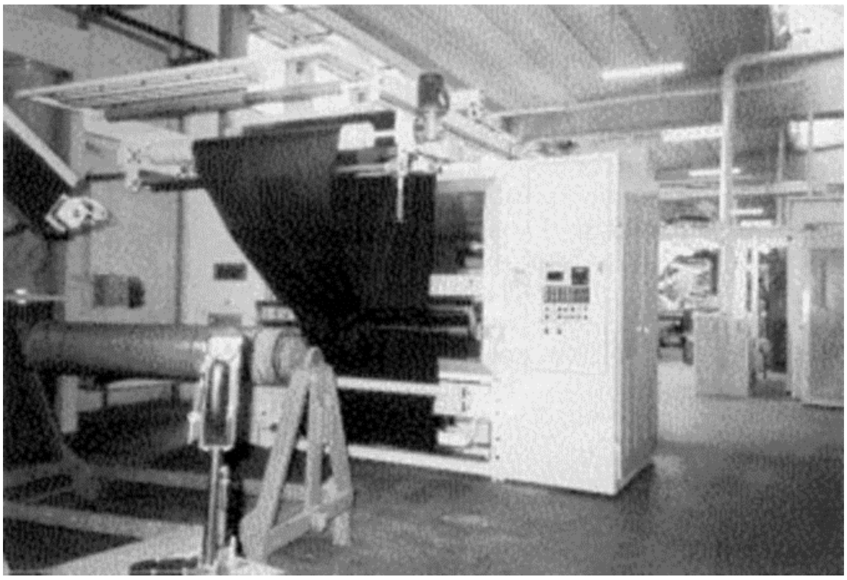


Fig. 160 Raising machine equipped with 2 rotary drums, each featuring 24 rollers

The raising machine shown in Fig. 160 is equipped with two overlapping drums, each one featuring 24 rollers, which can process two faces or face and back of the same fabric.
The drums assembled on a standard machine can rotate separately one from the other in the fabric feeding direction or in the opposite direction by carrying out a counter rotation.
In this model all the functions are carefully monitored and controlled by a computer system; in particular all the commands are driven by alternating power motors controlled by "sensorless" vector inverters. The control electric system features:

- PLC programmable controller for machine and alarms automation;
- touch-screen to program and update all processing parameters;
- the operating conditions of each single raising process (up to one million “recipes") that can be stored to facilitate the batch reproduction.

Furthermore, a series of special pressure rollers can be assembled on the feeding cylinders to prevent the fabric from sliding, thus granting an extremely smooth raising.
The raising process ability lies merely in raising the desired quantity of fibre ends without excessively reducing the fabric resistance.
For this reason, the technique applying the alternated use of pile and counterpile rollers is the most widely used since it minimises the loss of fibres from the fabric and the consequent resistance reduction.
Standard raising machines have been designed to work with fabrics powerfully tensioned essentially because they are not equipped with an efficient and reliable tension control. This gives rise to the effects detailed below:

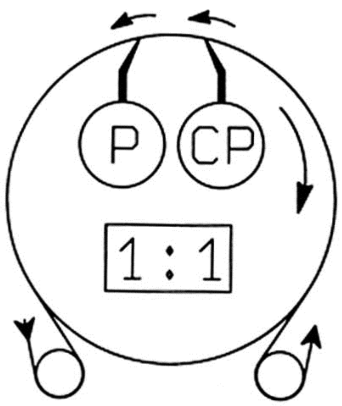
1) the contact surface between the fabric and the raising cylinders is quite small;
2) the clothing tips work only superficially on the fabric and the raising effect is quite reduced;
3) the fabric width is drastically reduced.

The above mentioned inconveniences have now been eliminated thanks to the last generation of raising machines, which reduce the number of passages and carry out the raising process by gently tensioning the fabric.

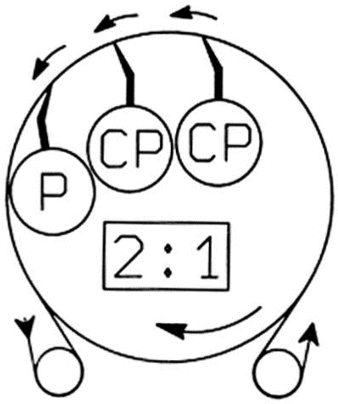
These new raising machines have been equipped with an extremely accurate and self-adjusting system for feed tension control; the relationships between the ratios of the roller relative speed of the cylinders are electronically controlled by a PLC.
The above mentioned parameters are constantly monitored and adjusted and a wider range of effects can be homogeneously carried out and reproduced; all this results in

- quality excellency with higher coverage and limited loss o fibres;
- higher production output with a reduced number of passages (up to 50%);
- consequent saving with lower costs per treated fabric unit.

A 24-roller machine can feature one of the following possible architectures :



1:1 Conventional system - 12 CPs + 12 Ps

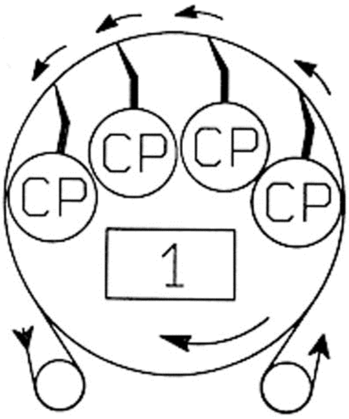


2:1 System - 16 CPs + 8 Ps

A greater pile density can be obtained with this system, since this machine features 4 extra CP rollers (performing as true ”raisers”), but the pile length is slightly shorter due to the reduced number of P rollers.

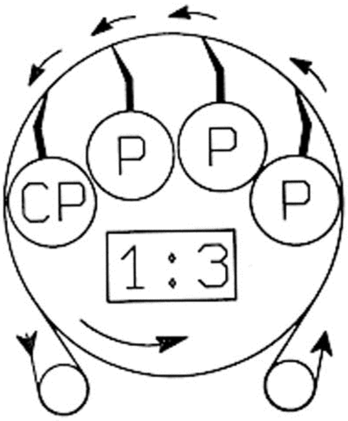
3:1 System - 18 CPs + 6 Ps

Same as above, but now the number of CP cylinders is still greater than 2. Consequently the hair pulled out is thicker, but its length is further reduced.
In most cases the shorter pile does not create any problem, since the raising process is followed by a shearing (cutting) phase.



System 1 – 24 CPs napping unit

This system is used for plush purposes, i.e. to felt the fibre end previously raised on special fabrics such as blankets, cotton and/or polyester plush and pile fabrics.



System 1.3 - 6 CPs + 18 Ps
This system is used to loosen the pile; the number of P rollers is higher than the one of CP rollers.
This system is mainly used to loose the pile on pile fabrics before the final shearing process.

Wool glazing

This special treatment is used to perform permanent finishing on wool fabrics after raising. The machine is made up of two different aggregates:

The **chemical finishing aggregate, which** includes:
- a vat containing water and silicones;
- a variable-speed extracting cylinder to reduce the quantity of liquid to be passed onto the fabric;
- a brush coated with horsehair adhering to the extracting cylinder and passing the liquid onto the fibre ends of the fabric, simultaneously combing and lining up the fibres.

The **glazing aggregate, which** includes:
- a fluted polishing cylinder (made of steel and coated with hard chrome) heatedby means of electric resistances at temperatures up to 220°C and four spiral grooves on which hard-steel combs are assembled. These combs have very fine teeth to enhance the efficiency of fibre ironing during the process;
- a felt sleeve, generally in wool, rotating at the same speed of the fabric, presses the fabric onto the polishing cylinder. The contact arc on the polishing cylinder can vary and the cylinder can reach a temperature of 130°C.

The fabric with the pile already brushed and wet comes under the polishing cylinder, which dries and irons the pile, imparting a lustrous appearance with a soft and smooth hand, also thanks to the silicones added to the starching vat; thanks to this process, the fabric acquires a hand similar to a valuable wool.
By adjusting the temperature and the speed of the polishing cylinder, the contact arc of the fabric on the cylinder and the contrasting pressure of the felting material, it is possible to obtain different finishing effects (from laid down pile to upright pile).

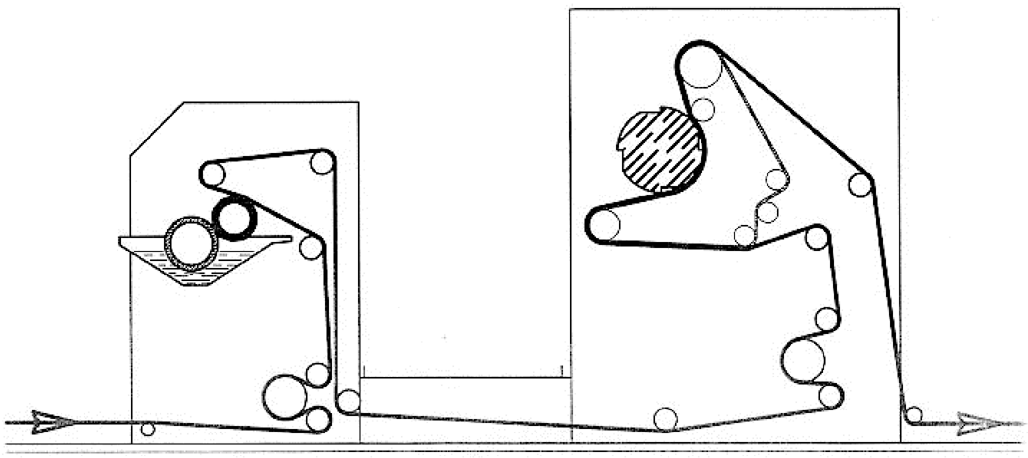


Fig. 161 Scheme of wool fabric glazing machine

Shearing

This cutting operation, complementary to raising, determines the height of the pile irregularly raised during the raising process; the resulting effect modifies the appearance and the hand of the fabric, which becomes velvet-like. The machine is made up of:

- velveting brush
- velveting table
- shearing cylinder equipped with helical blades
- fixed counterblade
- shearing table
- lubrication felt.

The fabric, after a brushing operation facilitating the raising, is fed on a shearing table forcing it to follow an acute angle direction. In this way the fibres raised by the cutting cylinder are correctly positioned to be sharply cut; the cutting cylinder rotates very quickly and carries out the first blade-cutting operation; the second fixed blade is represented by the doctor blade that stops the pile and cuts it. At this point the action of another brush adjusts uniformly the pile covering the fabric and the suction unit removes the sheared ends.
When the shearing is carried out on velvet fabrics, during the final brushing the pile is not only adjusted but also set by blowing overheated steam on the back of the fabric.
Obviously, to perform a perfectly smooth operation the shearing drum must not oscillate and must show a perfectly circular section.
Also the counterblade must have a sharp and perfectly even profile and the shearing table must be always positioned at perfectly uniform distance from the doctor blades, with no raised areas.
Depending on the desired length of the pile, the shearing table, the helical blades and the counterblade are perfectly adjusted and calibrated: the resulting effects depend on these adjustments (one tenth of a millimetre accuracy is allowed) and on the blade grinding.

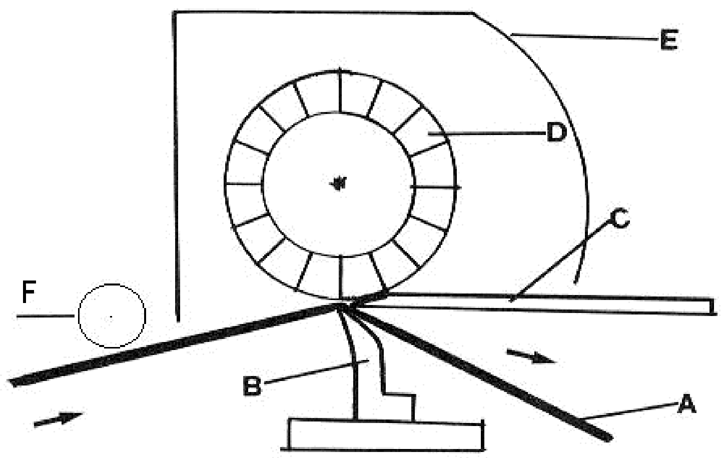


Fig. 162 Scheme of a shearing machine: A = fabric; B = wedge;C = counterblade; D = helical blades;E = suction unit; F = brushing drum.

The fabric passes under a rotating brush, which raises the pile and pushes it towards the fixed counterblade. The fabric is tensioned by means of special gears and slides on a bar provided with a cutting edge that keeps the fabric in a correct position and drives the pile through the two blades. The fibre ends are cut by the contact between the counterblade and the rotating helical blade; the contact point moves quickly on the whole width of the fabric following the cylinder rotation and

cuts the fibre ends between the two blades. Obviously the following cutting passages must be as close as possible to make the weaves on the fabric surface less evident. The distance of the following cutting passages depends on the number of blades assembled on the machine (from 16 to 24), on the cylinder revolutions per minute (from 700 to 1200) and on the feeding speed of the fabric: $D = V/g\ n$ (where (V) is the feeding speed of the fabric expressed in cm per minute, (g) is the number of revolutions per minute performed by the cylinder equipped with blades, and (n) is the number of the cylinder blades).
To avoid overheating due to the friction between the helical blades and the counterblade, a woollen felt (which is usually covered with a special lubricating oil every 2/4 operating hours) is assembled on the cylinder. The shearing aggregates must be controlled and ground at regular intervals. The shearing height is generally adjusted by raising/lowering the shearing unit with respect to the shearing table and only a few hundredths of millimetre accuracy is allowed. These machines also include an electropneumatic device, which automatically makes the seam slide under the velveting and shearing unit.
The cuts will be slanting to the fabric. To obtain a more even fabric surface, the shearing operation must be carried out with two cylinders equipped with helical blades arranged in the opposite direction, or with an even number of passages carried out with cylinders rotating each time in the opposite direction (crosscuts).
Both shearing and raising machines must be equipped with devices which decrease the fabric tension (shearing machines) or raise the blades (raising machines) when the seams joining the cloths pass through the machine; this prevents the fabric from tearing and avoids undesirable machine stops.
Also patterns may be cut into the fabrics through shearing as in the case of raising, by using special fixed or mobile blades.

Dimensional stabilisation

The compacting process (Sanfor process) gives the fabric a controlled compression shrinkage, which eliminates distortions originated during previous processes. The fabric finished with this treatment keeps its shape also after repeated washing, thus providing an excellent dimensional stability of the textile article. The fabric is fed into an opener/tension-adjusting device, and subsequently passes through a wetting unit where the quantity of water necessary for swelling the material is sprayed on the fabric.
A steaming treatment can be carried out by passing the fabric onto a heated cylinder, which allows the water diffusion in the interior of thefibre and completes its swelling.
The textile material passes to a stenter which gives the fabric the desired width and is then fed into the rubber-belt squeezing unit.
The fabric shrinkage is carried out with several simple operations: the rubber belt pressed between the squeezing cylinder and the drum is stretched and, once out of this squeezing unit, takes again its original shape. The fabric is let adhere to the rubber belt in the squeezing area and, since it can slide more easily on the heated and mirror-polished surface of the drum than on rubber, the fabric is forced to follow it during the subsequent shrinkage.
The resulting effect is a continuous and steady sliding between the drum and the rubber belt and consequently between the drum and the fabric. Since the elastic elongation of the rubber belt depends on the intensity of the pressure exerted by the squeezing cylinder, each pressure variation corresponds to a shrinkage variation.
Therefore the higher the pressure, the greater the shrinking effect.

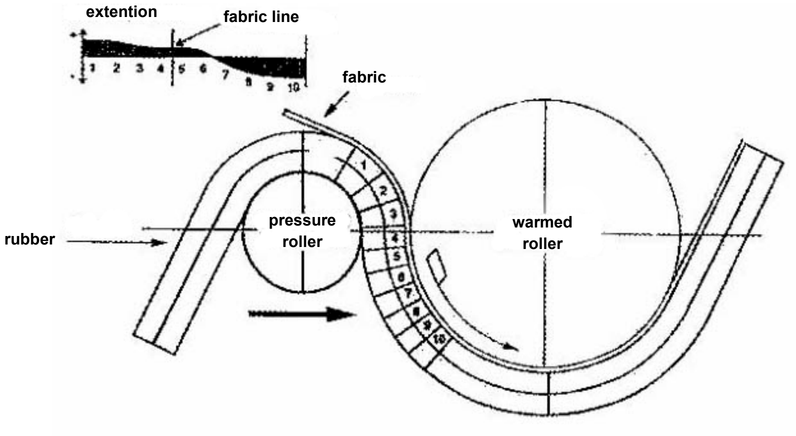
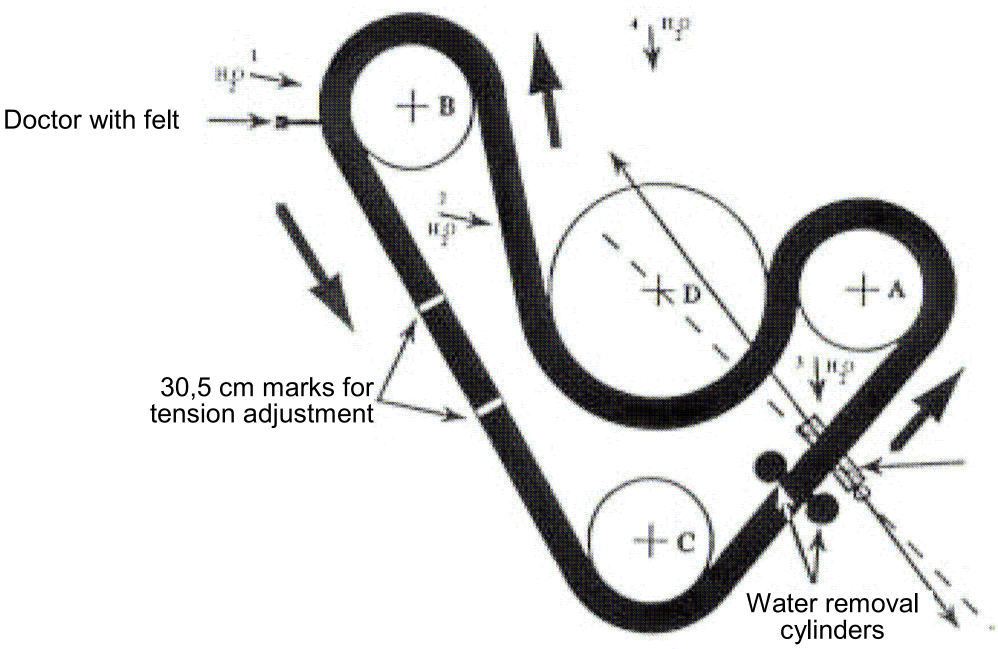


Fig. 163 Compacting process

After leaving the squeezing unit, the fabric is sent out to the drying unit (180°-190°) with the slightest possible tension. The fabric is fed into a felt calender, which sets the shrinkage.
Immediately after the compression compacting, the fabric must be subjected to the slightest tensions and the moisture contents must not be excessive.



A pressure roll	*1. Outer cot cooling nozzle*
B Tensioning roll	*2. Inner cot cooling nozzle*
C Lower roll	*3. Inner cot lubricating nozzle*
D Heated roll	*4. Emergency cooling nozzle*

Fig. 164 Scheme of shrinkage area

Tubular knitted goods canbe treated on stenters (to impart dimensional stability) only after the cutting operation and possible bonding. Drying and dimensional stabilisation of tubular knitted goods can be obtained by passing the relaxed fabric into vibrating belt dryers and by steaming them in the final path.

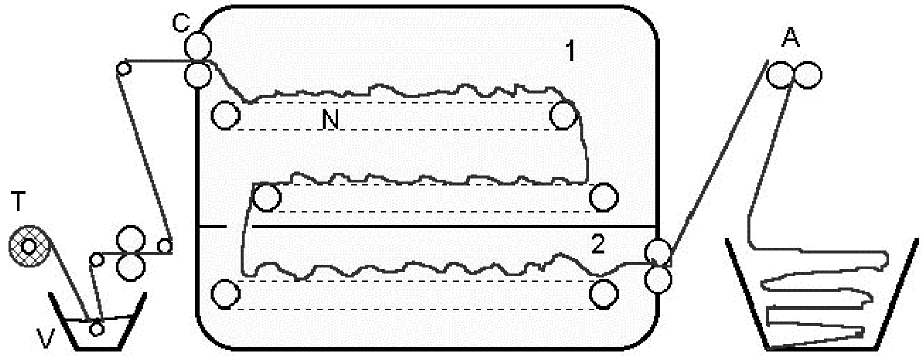


Fig. 165 Compacting process for tubular knitted fabrics

The fabric (T), wet or dampened with a solution of softening agents in a vat (V), is laid down, overfed by a little calender (C), on the metal-mesh vibrating conveyor belts (N) of a dryer. On the first two conveyor belts, the fabric is dried with hot air (1) while vibrations make the fabric shrink freely; on the third conveyor belt, a steaming treatment (2) is carried out to set the dimensional stability, increase the fabric bulk and give a soft hand to the fabric. The fabric is then folded in a special folding unit (A). If cutting and bonding units follow, a compacting machine can be added.

Setting

The fixing or, better said, setting treatments of wool fabrics have the purpose of limiting, during the processing phases carried out in warm/humid medium such as scouring, dyeing and clamping-free steaming, undesired effects as: slight felting, creases, fold marks, dimensional and appearance variations due to yarns and wool fibres relaxation. The setting of wool fabrics can be operated both with physical and chemical treatments.

Physical setting treatments

These treatments can be effected on wet fabric (crabbing) as well as on dry fabric (decatizing in autoclave), favoured by the thermoplastic properties of wool. It is well known that steam, and even more distinctly hot water, affects in two ways the wool fibre:

- modifying the morphologic structure of the cortical cells, which stretch out and slip the ones on the others
- permitting the hydrolysis of cystine (this is, with its two sulphur atoms, the main factor of elasticity), which is transformed into compounds having one sulphur atom only and liberating from the fabric hydrogen sulphide which releases its typical smell. In this way the a-keratin (the main natural component of wool) is transformed into the much less elastic structure of b-keratin.

This mechanism of chemical/physical transformation can be obtained by treating wool in water at over 100°C for a certain time and by blocking the b-keratin produced through a heavy thermal shock.

This shock, besides preventing the inversion of the chemical reaction, sets the new physical structure of the cortical cells (scales), swollen up and stretched out owing to high temperature pressure; the consequence is the sliding of the scales the ones over the others (as we all know, the wool fibre has 3 layers of scales), which prevents that the fibre, by resuming its former physical-chemical characteristics as a-keratin, regains completely its natural elasticity; in this way the wool fibre becomes insensible to the subsequent steam treatment during the finishing and making-up processes and lends to the fabric a structure of permanent stability.

We wish in particular to stress the fact that the setting degree in water depends not only from the temperature, but also from process duration; therefore it is a mistake to schedule one and the same setting speed and temperature on all kinds of fabric.

Crabbing

Crabbing requires usually an equipment provided with steam-heated (130-140°C) drum, which is partially wrapped around by a waterproof technical cloth.
The treatment takes place in three phases:
- in the first phase, the fabric is wound up on the setting roll by means of a pneumatic device which automatically adjusts the winding pressure and maintains it constant through every variation of fabric roll diameter;
- in the second phase, the circulation around the drum of pure hot water or of an aqueous solution containing reducing agents like bisulfit takes place. Part of the water absorbed by the fabric in contact with the heated drum is transformed into steam. This steam is maintained in contact with the fabric thanks to the waterproof property of the silicone treated cloth. Also another element contributes to this condition of high temperature in the presence of steam, namely the mechanical pressure which can be exerted on the fabric either by proper pressure rolls positioned around the drum, or by high tension operated on the waterproof cloth. The result of all these components (high temperature – steam – mechanical pressure) permits to attain an adequate setting level;
- in the third and last phase, a quick emptying of the hot water, replaced by constantly cold water, takes place.

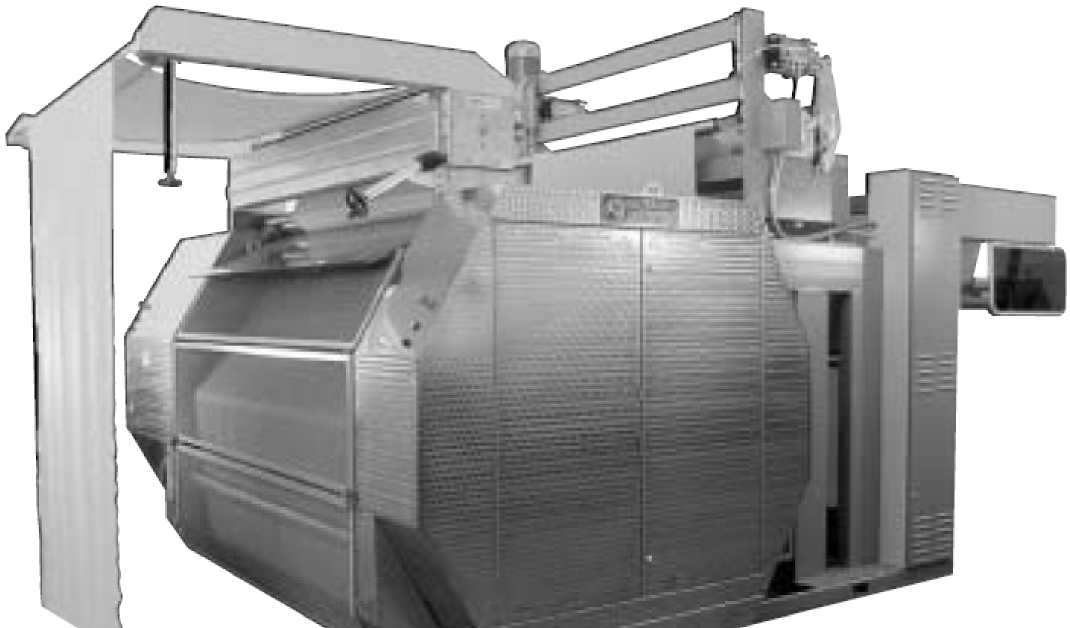


Fig. 166 - Crabbing machine

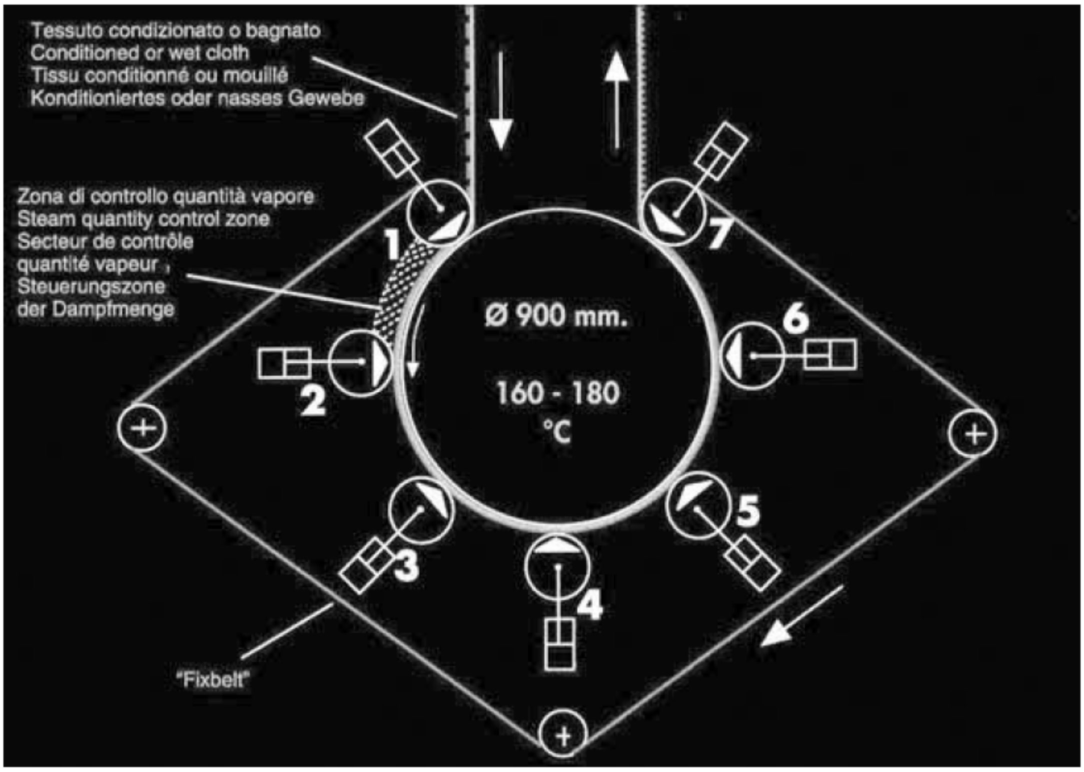


Fig. 167 Scheme of a crabbing machine

Main technical characteristics of the crabbing machine:

- drum diameter	900 mm
- max. drum temperature	180°C
- processing speed	0-35 m/min
- fabric width	1900 mm
- absorbed power	35 Kw

Conticrabbing

This machine is devised for continuous fabric setting. Unlike all existing fixing systems, it does not make use of rubber bands or of printing blankets, which would require expensive periodical replacements. Setting is obtained without any need of chemical additives, but draws on the chemical/physical properties of wool itself.

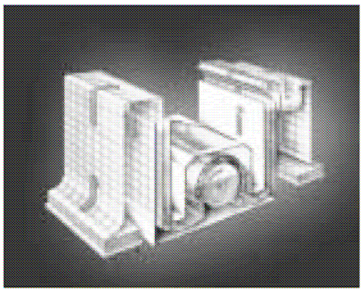
This process yields, besides setting, following properties:

- better fabric quality, thanks to softer and more elastic (nervous) handle
- higher lustre of the fabrics after dyeing (which evident characteristic is highly appreciated)
- removal of creases and shrinkages in the iron-on phase of garment making-up process.

The fabric, guided by expander rollers, enters a pre-scouring basin, which can be used for various purposes:

1) to wet the dry and clean fabrics before their entering the barometric column
2) to mix acetic acid so as to prevent colour bleeding when treating fancy fabrics
3) to pre-scour not excessively soiled fabrics, with continuous water overflow.

After passing through squeezing rollers, the fabric penetrates through three barometric columns containing water in the bottom and steam in the top, with tube nest plates operated by indirect steam.
The fabric is conveyed to the main drum (2 m diameter) by a spreading system with extensible staves which ensures its perfect spreading, as well as by a motorized spiral-shaped roll designed to enroll selvedges; this introduces the fabric to the calendering roll made of special rubber (300 m diameter, up to 2 Kg/sq.cm. pressures) pressing it against the main drum.
The fabric conveyed by this large drum is subjected in its bottom to the action of water at 110-115°C and in its top to the action of saturated steam, which in the interspace between the drum and the superheat tube nests provides it with a “thermal shock” of over 140°C.
Successively the fabric reaches the delivery column, which is equipped with special ailerons to slow down the thermic exchange and to spread it via hydraulic means.
At the top of the column, the fabric is again extended by a special spreading system with extensible staves and by two motorized spiral-shaped rolls in inoxidizable steel, which have the task of enrolling the selvedges before the fabric enters through the squeezing rollers.
After these squeezing rollers operating at pressure of max. 4000 Kg., the fabric enters the thermal shock basin, reaches through a rocking roller synchronism the last pair of 4000 kg squeezing rollers and is finally folded.



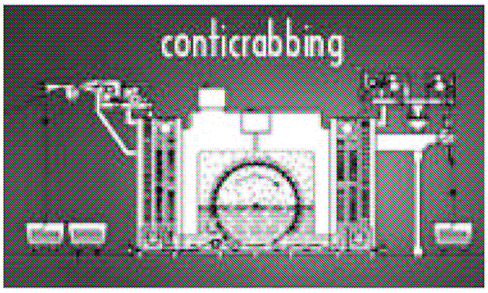


Fig.168 Conticrabbing machine

Production speed: 15/25 m/min
Capacity of pre-scouring basin: 900 l
Capacity of main vat: 5500 l
Capacity of thermal shock basin: 500 l

Decating

This process is mainly carried out on wool by exploiting its elastic properties in hot and wet conditions by the direct action of the steam on the fabric. This treatment gives the processed fabric the following characteristics:

1) dimensional stability;
2) setting of pile after raising;
3) reduction of possible glazing effect after calendering, thanks to the swelling caused by steam blown on fibres;
4) modification of the hand, which is much more consistent after the treatment;
5) pre-stabilisation to autoclave dyeing

This category of treatments does not include the stabilisation of wool fabrics such as potting, where the dimensional stabilisation is obtained thanks to the "plasticisation" phenomenon occurring when the wool fabric is immersed in hot water.
On fabrics made with other fibres, the same treatment can be carried out as "steam ironing" alternatively to the calendering treatment, when an excessive "glazing effect" could result from the treatment.
The steam decating, which is also referred to as dry decating, is carried out on decating machines in one continuous treatment or two discontinuous ones, according to the following operating techniques:

- drum decating (alternated at atmospheric pressure);
- autoclave vacuum decating (KD);
- continuous decating.

Alternated decating

In discontinuous decating processes, the fabric is wound, together with the “satin” (2) or “beaverteen” blanket (1) – on a large perforated drum (90 cm diameter) on which some meters of blanket or similar cloth have been previously rolled.
By using large rollers, it is possible to wind the same quantity of cloth with a lower density of the roller, to allow the steam imparting a more uniform effect and reducing the differences between the beginning and the end of the piece.
The steam, at a temperature that can reach 130°C and a pressure of up to 6 bars, is forced into the cylinder through the fabric roll (i.e. it is forced through both fabric and blanket) for a time that can range from 1 to 3-4 minutes, according to the desired effect. The steam is then exhausted by means of a pump.

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(1) Beaverteen: raised technical fabric, used as a blanket in fabric decating process when the desired effect is a bulky hand and a dull appearance.
Technical features of the most common types of beaver teens: width ranging from 176 to 178cm, weight varying from 190 to 600 gr/m^2 2; thickness 1.5-2 mm; structure: polyester warp, cotton weft; polyamide warp, cotton weft; warp and weft 50% polyester/50% cotton.

(2) Satin: technical textile used as a blanket in discontinuous decating (in drum or autoclave).

The main characteristics of a “satin” are the following:
1) dimensional stability;
2)consistent steam permeability;
3) resistance to chemical agents and to steam;
4) no negative side effects.
The most common fibre structures are the following:
1) polyester (65-50%)/cotton (35-50%), weft and warp;
2) 65% polyester warp / 35% cotton; 65% cotton warp/ 35% polyamide;
3) warp and weft 65% cotton / 35% polyamide.
The life of a “ satin” depends upon:
1) the presence of chemical products on the fabric;
2) the quality of the steam.

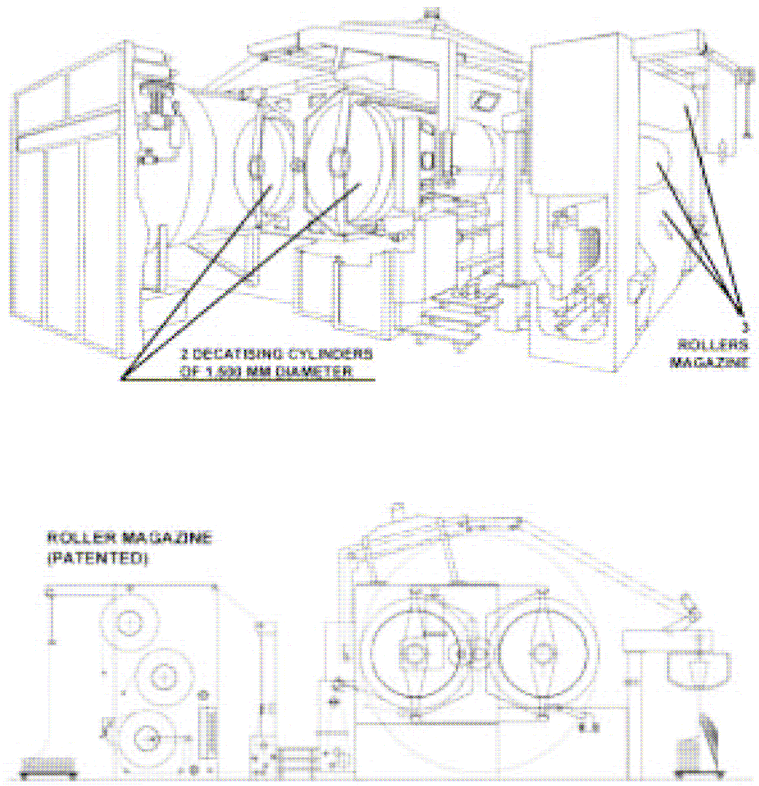


Fig. 169 Loading system of a pressure decating unit

Autoclave decating (Kessel-Dekatur)

Thanks to the possibility of reaching higher temperatures (130°C) and high pressures (up to 2 bar), the setting effect is markedly more durable than when working at atmospheric pressure. This treatment is today well established and commonly used to give dimensional stability to all combed fabrics and also to some carded ones. The machine can be divided into two main compartments: the fabric take-up area and the horizontal autoclave. Recently, semi-automatic systems have been successfully developed and improved thanks to multiple-position stations, which allow preparing a new roller and unloading the treated one, while a third roller is undergoing the decating treatment.

It is noteworthy that the setting effect is directly proportional to the increase of process time and steam pressure and consequently to temperature. The increase of both factors causes a marked yellowing of the wool together with a progressive deterioration of the peculiar qualities of the fibre (resistance, elasticity and soft hand).

Continuous decating

The need to speed up the processing cycles has led to the development of continuous systems, which give better output rates, no piece end-to-end differences, no marks on the fabrics due to the seams required to sew together the two ends of the piece and sometimes moiré effects. The only disadvantage is a less powerful effect given by the treatment; in particular an unsuitable stabilisation for all products.
The continuous decating process carried out under pressure allows a permanent setting of the wool fabric, which is obtained through a first processing step with saturated vapour under pressure (which can reach a temperature exceeding 135°C), while a second cooling step grants the surface and dimensional stabilisation.

For handling purposes, the fabric is compressed between a large perforated roller, coated with a heavy fabric and a thick endless blanket made of dense cotton/polyester felt. All along its path the fabric is treated (using different systems) with steam supplied by means of special delivering units assembled under the conveyor belt in the lower part of the cylinder, and subsequently cooled with air. The intensity of the treatment can be adjusted by adjusting the process speed, the pressure between the cylinder and the conveyor belt, the moisture degree and the steam pressure.

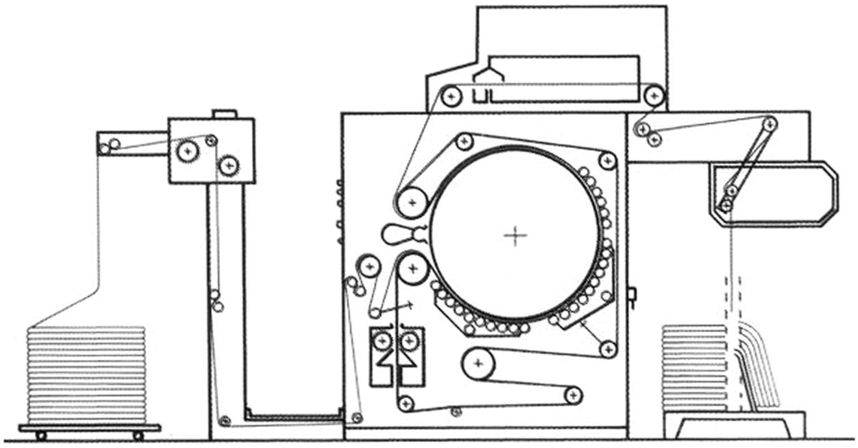


Fig. 170 Scheme of fabric path in the continuous pressure decating process

Chemical stabilization treatments

The products generally used are organic reducing agents such as aminosulphites, which develop their reducing power at muggy room conditions. These reactions are redox processes which involve the cystinic bridges of keratin and can be carried out both on wet treatment machines and through padding followed by drying and decating process, which last originates a thermic shock that completes the flat-setting effect.
If padding is carried out, it is necessary to use wetting agents and to store the substrate for some hours before decatizing, in order to ensure uniform moisture and a successful treatment.
The risks resulting from the stabilization processes can be:

- a different setting effect from end to end of the fabric piece,
- in particuar in case of fabrics wound on beams;
- a different setting effect from fabric centre to selvedge, which more often than not is caused by a different tension of the selvedges in respect to the centre of the piece;
- a moiré effect due to unevenness of the ground colour, which comes in view in particular with treatments which require a tight fabric winding (potting treatments);
- an excessive yellowing of wool, due to alkaline residues existing on the fabric or to a not too vigorous decating treatment in autoclave.

Steaming

The tensionless steaming process of wool fabrics is the most widely used technique to obtain a good dimensional stability to ironing with steam press.
The steam action involves the hygroscopic swelling of the fibres with a subsequent relaxation or shrinkage of the fabric, which recovers its "natural" shape.
The steaming process eliminates also all the residual tensions. The machines used to carry out this treatment are called tensionless steaming machines (tensionless steaming) or steaming-shrinking machines.
The tensionless steaming units can be divided into four main sections:

1) feeding section where the fabric is laid on a continuous conveyor belt by means of an overfeeding system coated with a technical fabric made of synthetic material, stable in regard to the action of heat, featuring such a weave to ease passage of steam. It generally vibrates for a better relaxation of the fabric and keeps it quite suspended inside the steaming tunnel.
2) steaming area with one or two steaming tunnels with a suction system.
3) cooling area equipped with a suction unit assembled under the conveyor belt to eliminate the residual moisture.
4) fabric take up area, where a dandy roller or an optical control system adjust the speed to prevent any stretching of the rolled or folded fabric.

Technical innovations applied to the steaming processes aim at obtaining a better and final relaxation of the fabric and a reduction of the steaming stage, which requires a great quantity of steam (which is mostly dispersed outside through vents) and long processing times, since good results can be obtained only by keeping the fabric in contact with steam for a long time. The various machine manufactures have developed special systems to cut processing times and steam quantity and obtain an optimum relaxation of the fabric. The system shown in Fig. 171 features a programmed and controlled dampening system assembled before the steaming tunnel.

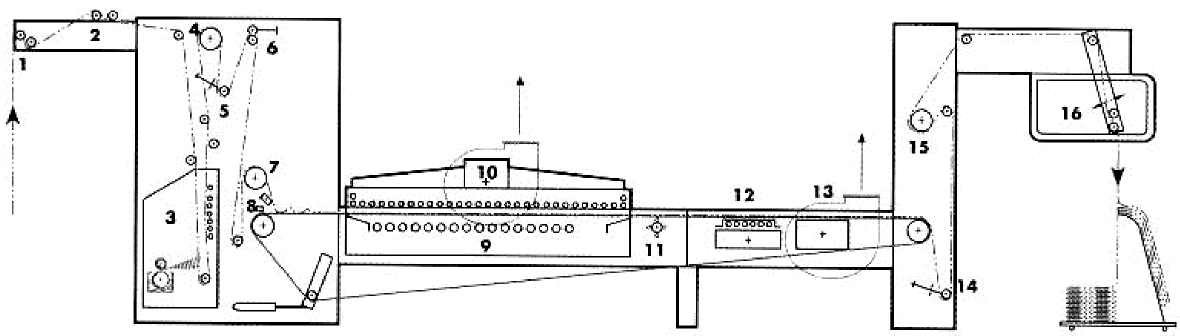


Fig. 171 Steaming-shrinking unit: 1) double braking bar; 2) fabric centring device; 3) dampener; 4) adjusting cylinder; 5) compensating cylinder; 6) moisture sensor; 7) feeding cylinder; 8) feeding sensor; 9) steam application field; 10) suction hood; 11) vibrating device; 12) blowing unit; 13) suction unit; 14) fabric unloading regulator; 15) fabric unloading cylinder; 16) variable folding device.

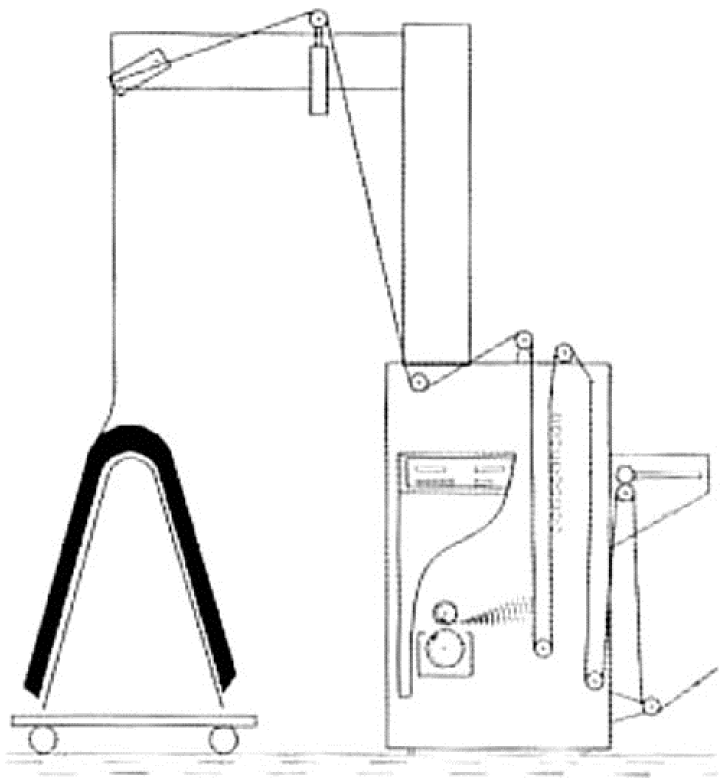


Fig. 172 Detail of the automatic fabric dampening machine

The dampening system has been introduced into the steaming unit for the reasons detailed below.

- Steaming generally tends to reduce the moisture percentage dispersed in the fabric and therefore the pre-dampening operation grants a recovery ratio of the fabric after the treatment certainly better than the one obtained with a standard system.
- The moisture dispersed in the dampened fabric fed into the steaming system is transformed into steam thus providing better shrinkage and relaxation results.
- Commercial tests have shown a remarkable steam saving obtained thanks to the vaporisation of water previously sprayed on the fabric.

The set up of the steaming-shrinking-crabbing unit has allowed great steam saving, a remarkably increased output rate and high-quality final results.
The basic elements characterising this new type of steaming unit are detailed below:

- the steaming tunnel with new design and architecture, grants an efficient air exhaust and the addition of a saturated vapour compartment with almost no-oxygen prevents any possible fabric defect caused by standard steam feeding units;
- the steam is fed and controlled according to the real consumption, thus avoiding any dispersion inside the tunnel;
- the temperature is controlled and adjusted according to the type of fabric and fibre to be treated;
- any outlet exhausting in the atmosphere has been eliminated and consequently all heat dispersion has been eliminated.

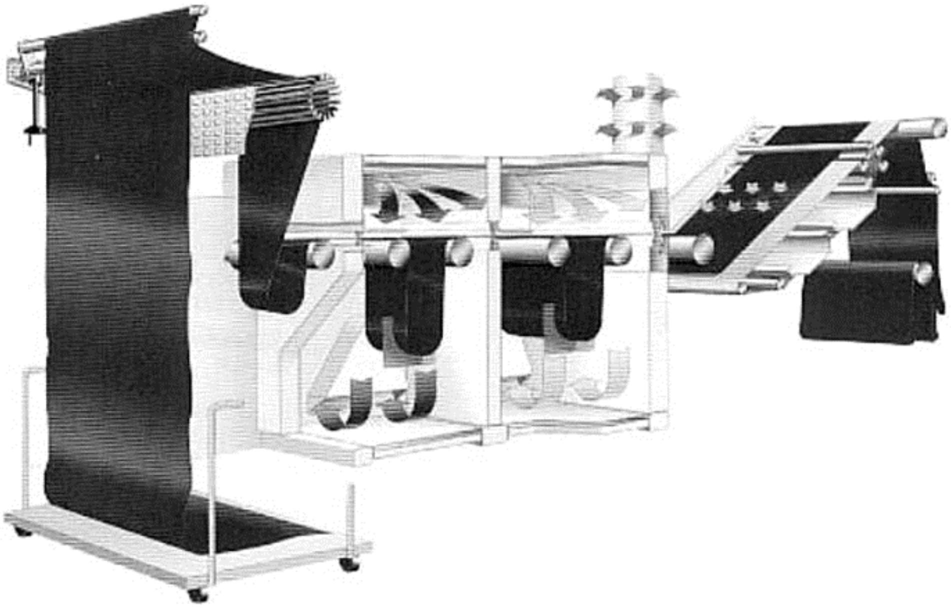


Fig. 173 Festoon steaming-shrinking machine

In another type of steaming machine the fabric is exposed to the steam action with tensionless feeding thanks to a suspended fabric system which avoids the use of a conveyor belt.

The festoon system has the following advantages:

- energy saving with the same relaxation effect thanks to the steam recirculated into the steaming compartments;
- lower processing temperatures, greater quantity of water vapour;
- longer dampening times with the same machine speed, due to a greater quantity of fabric fed into the "hanging fabric compartments ";
- automatic self-adjustment of the tensionless take-up of the fabric inside the compartments, thanks to the shrinkage controlling system which monitors each single cloth and to the improved driving system.

The system includes a double cooling compartment with forced ventilation (thermal shock) in the final section aiming at simultaneously cooling down the fabric and relaxing the internal tensions of the fabric structure.

Chemical finishing

By applying chemicals of different origins, a fabric can receive properties otherwise impossible to obtain with mechanical means only.
Thus chemical finishing treatments produce the following:

- they allow the stabilisation of fabrics already subjected to mechanical finishing processes, such as calendering;
- they give fabrics some properties (e.g. flame retardancy and water repellency), which would be otherwise absent

The products used can be classified as follows:

- **Natural** (adhesives, fats, oils, starches)

- **Artificial** (modified starches, modified cellulose)

- **Synthetic** (synthesis products) including: N-methylol derivatives (thermosetting, reactants), linear reactants (carbamates, epoxy resins), thermoplastic polymers (vinyl, acrylic, polyethylene), polyurethanes and silicones.

This classification, helpful for students, does not coincide with the products actually sold on the market since these products are blends containing also catalysts and auxiliaries which interact and produce complementary effects. It is therefore necessary to underline how chemical finishing can affect the textile product by altering its mechanical properties, sometimes changing the colour shade or its original colour fastness.
Different techniques are available for applying the above mentioned finishing substances: by solution, dispersion, and emulsion, pad wetting, exhaustion, coating, spraying, etc.
The most appropriate technique must be carefully studied for each fibre type, and the most suitable chemical finishing process applied to obtain optimum results and grant a reasonable safety margin for any possible error.

Finish application on fabrics

The operations to be carried out when applying the finish to a textile substrate are mostly conditioned by the structural and hygroscopic properties of the material to be processed, by the desired effects, by the physical and chemical nature of the elements that make up the finishing substance and by the machine’s output rate. In textile finishing, we can distinguish between five main application techniques:

a) padding;
b) spraying by means of atomisers;
c) exhaust process in treatment liquor;
d) coating carried out by means of doctor knives;
e) controlled application of low liquor quantities.

Padding is by far the most common among the various finishing techniques.

Padding

This is certainly the most popular process for both the most conventional and innovative finishing treatments. The machine used for this process can be referred to with various definitions such as padding unit, squeezing unit, etc. After ensuring that the textile substrate can be padded by evaluating its mechanical and structural properties, this technique can be applied to carry out all wet finishing operations, except for some cases (see pad dyeing for details about the machinery used).

Spraying

The application of finishing substances by spraying is used for carrying out gentle finishing processes which leave on the textile material a small concentration of products, and is particularly indicated for applying softening, anti-static and anti-mildew agents. For a good and homogeneous penetration and diffusion of the finish in the textile material, it is better to let the sprayed and wound fabric rest for some hours before drying.
In the last few years, a very important field has been developed in the textile sector, i.e. the production of webs made of synthetic fibres. For this particular type of product, the resin-coating process is carried out only by spraying the finish directly on the fibrous substrate and by generally applying synthetic resins in aqueous emulsion.

Exhaustion

The treatment of yarns or fabrics in exhaustion liquor is recommended above all when stable chemical products are applied on the textile substrate.
The manufacturing process undergone by the material is useful to precisely evaluate the best method for applying the finish, for example on hosiery or tubular knitted goods. From a chemical point of view, the most suitable products for the exhaust process are those with cation-active properties. In particular cation-active softening agents are often applied with this process, as well as paraffin- and wax-based emulsions, and more recently, cation-active polymer emulsions.

Coating

At present, after the launch and diffusion of synthetic resins, the so called "coating and bonding" applications have been experiencing an extraordinary growth, above all in Italy.
Coated and bonded fabrics are now simply classified, according to their end use, i.e. for garments, upholstery, draperies and tapestries, footwear, leather goods and technical articles.
Generally the process starts from a fabric or from a non-woven fabric as a "backing".
All fibres can be used, from light silk to linen and hemp, from synthetic fibres to glass fibres.
As regards the resins used for the coating layer, manufacturers once employed only natural substances, but are now using almost exclusively synthetic polymers of high molecular weight.
Today manufacturers are constantly in the search for coating substances that are more and more elastic, able to withstand different mechanical stress and washing conditions, and above all resistant to wearing and weather agents.
These coating polymers are bonded to the fabric backing by means of calenders, in the form of thin sheets or are mainly spread in the form of aqueous dispersions or solutions in solvents.
The characteristics and the properties of coated fabrics depend on the chemical structure of the coating resins applied and the type of backing fabric used.
The coating layer undoubtedly plays the most important role for appearance, hand and resistance properties: its elasticity, its behaviour at high and low temperatures, its resistance to abrasion, to solvents and to the effect of ageing and weather agents, depend on its chemical composition as a substance with a high molecular weight and more or less thermoplastic qualities.

The coating technique

Coated fabrics are divided into specific categories according to the following scheme:

- fabric based on natural, artificial and synthetic fibres;
- coating layer of natural or synthetic resins.

The coating layer can be obtained with the following processes:

1. bonding with thin resin film;
2. direct coating with resins;
3. indirect resin coating with the transfer technique.

In the first process method, now scarcely used, the fabric is bonded to its fabric backing on special calenders.
This process is still used today to manufacture tablecloths by applying a thin PVC film to the fabric.

In the direct coating process, the resin is levelled directly on the fabric by means of a doctor or of a cylinder with the following methods:

- air-pressed doctor;
- belt/doctor combination
- cylinder/doctor combination;
- "reverse-roll" cylinder

Since the fabric, in all the above mentioned cases during the coating, drying and winding operations is always subject to warp wise tension, these coating methods can be only used on compact or stretch-resistant fabrics.
Obviously these methods cannot be used on knitted goods. During the air coating process and the belt coating one, the quantity of resin spread is relatively small and the desired thickness can be achieved only by applying successive layers, each one stabilised with an intermediate drying stage.

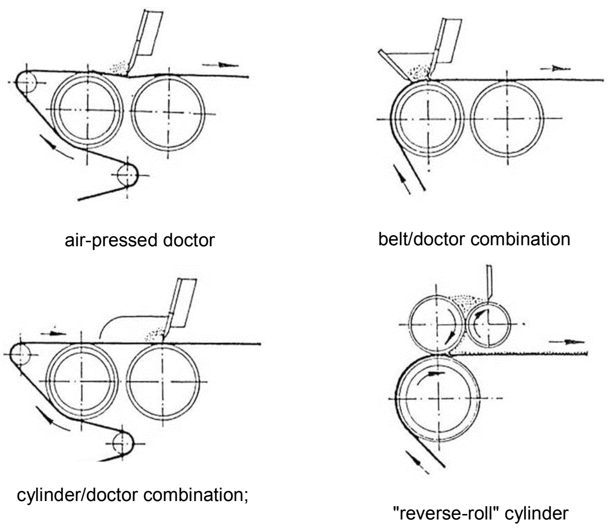


Fig. 174 Various types of doctor coating

The blades can have a more or less rounded profile; the quantity of resin spread is measured in grams per square meter of dry substance and is determined by the dry content of resin, by the coating speed and by the knife profile.
The greater the process speed, the smaller the quantity of resin spread; the sharper the knife, the smaller the quantity of resin spread on the fabric. This coating method is used to produce waterproof fabrics for rainproof textiles, umbrellas, tapestries and technical items. The most commonly used resins are the acrylic resins in solvent or aqueous dispersion and single or bi-component polyurethane resins.

With the reverse-roll cylinder method it is possible, within certain limits, to apply a thick coating layer, i.e. greater quantities of resin to fill a specific gap. In cylinder coating, the doctor knife usually has a finger's nail profile and the quantity of resin spread is measured in grams per square meter of dry substance or in hundredths of millimetres of coating layer thickness.

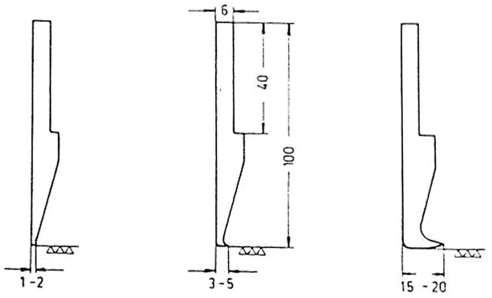


Fig. 175 Knife-shaped doctor blades

A direct coating unit consists of a series of coating heads alternated with drying ovens or tunnels, each one with cooling cylinders at the exit. The drying temperatures depend on the type of resin used, whereas the coating speed is determined by the length of the drying ovens, the air exchange, the coating system and the rheological properties of the resins applied: the reverse-roll method allows very high coating rates up to 70 m/min compared to the 15 to 18 m/min of other methods.
The reverse-roll method is applied to the following items:

- raincoats;
- waterproof canvas;
- coated fabrics for leather goods;
- coated fabrics for garment and upholstery;
- reverse coated fabrics for wall coverings;
- coated fabrics for footwear.

In the indirect coating technique, the coating material is first spread on a special paper (the so-called release paper) and is then transferred onto the backing fabric. The coating layer consists of a layer of resin spread directly on the paper and of a second layer of resin, which acts as bonding agent between the first layer and the backing. The backing can be of different materials with different properties. The release paper, which must be compatible with the resin applied, can be glossy, matt, smooth or embossed.
The steps to be carried out in an indirect coating process are the following:

- application of the first resin layer on the release paper (1st coating head);
- drying (1st oven);
- cooling;
- application of the second resin layer (adhesive, 2nd coating head);
- bonding to the backing (woven of knitted fabric, etc.);
- drying (2nd oven);
- removal of the coated fabric from the paper and fabric winding up;
- paper winding up.

The paper coating step is carried out using a cylinder and nail-shaped blades . The coating speed is relatively low and varies according to the resins to be applied; it can range from 4 to 20 m/min.
With this coating technique it is possible to manufacture a number of different articles of different appearance and hand. The appearance of the coated surface depends on the type of paper used (glossy, , smooth or embossed), while the ultimate hand properties are determined by the resin quality and quantity, the adhesive agent applied, the backing fabric and its preparation.
Here are some substrates that can be processed with the indirect coating technique:

- imitation leather for upholstery and apparel;
- imitation leather for footwear;
- imitation leather for suitcases and leather goods.

Controlled application of small liquor quantities on fabrics

Water is the most common medium used for applying the finish, and must be subsequently removed from the textile material after the treatment. A drying process is quite expensive. Therefore, to avoid additional costs, new techniques have been developed that allow a controlled application of limited quantities of the finish liquor. In fact, most of the water on the fabric surface or between the fibres can be eliminated with mechanical hydroextraction processes (centrifuge, suction, squeezing, etc.) but these processes will hardly remove the moisture dispersed in the capillary spaces inside and between the fibres.

In hydrophilic fibres (for example cotton), the limit of residual water that cannot be eliminated by means of a mechanical process ranges from 40% to 50%.

To obtain a homogeneous distribution of the finish in the fabric it is (theoretically) necessary and sufficient to only saturate the capillary areas of the fibres.

The quantity of solution corresponding to the water necessary for a complete swelling of the amorphous areas of the fibres is called "Critical Add on Value" (CAV) and is determined by the fibre nature and by the fabric structure.

Following the application of greater quantities of solution, during the drying process unstable finishing products can migrate towards the surface of the fabric, thus leading to inconsistent distribution of the finish on the substrate (internal yarn areas are poorer of finish.).

On the contrary, for an optimum application from both a technical (penetration and uniformity) and a cost-efficiency point of view (minimum energy consumption for drying), it is necessary to apply a quantity of solution equal to – or slightly exceeding – the CAV.

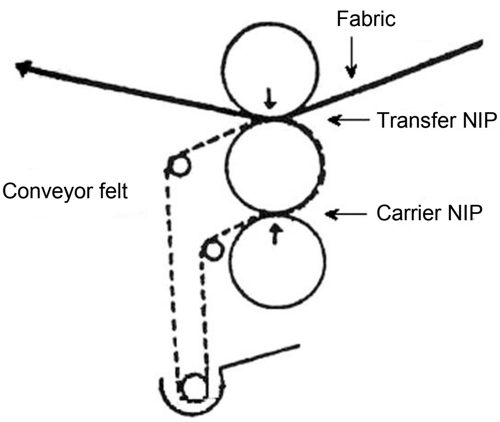


Fig. 176 Padding mangle

For cotton, this means that only 30-35% of the liquor needs to be applied. The various techniques are briefly described below.

1. **Liquor transfer**: a continuous felt is impregnated with the finishing solution and then squeezed between two rollers with a pick up rate of about 70%. The fabric to be treated is made adhere against the felt in a second squeezing unit. The squeezing pressure transfers to the fabric about half the liquor in the felt. By controlling the pressures in the two squeezing points separately, the quantity of liquor applied to the textile material can be accurately controlled and the variations per square meter of the fabric (within a certain range) can be evaluated with precision.

2. Finish printing: a finely engraved roller is partially immersed in the finishing liquor. The liquid in excess is removed by means of a doctor knife.

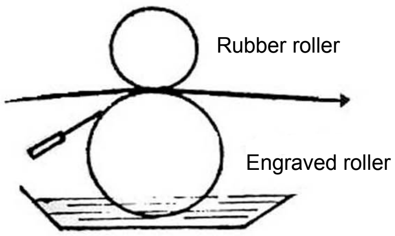


Fig. 177 Finish printing

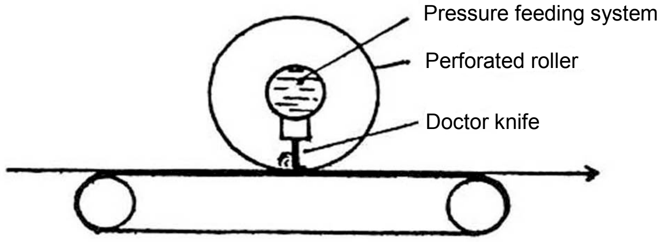


Fig. 178 Foam systems

The liquor remaining in the engraved roller is then transferred to the fabric by means of the pressure exerted by a second roller. By using special gluey finishing solutions, it is even possible to perform printing processes with hollow rollers. (See hollow-rollers printing.)

3. **Foam finish**: small quantities of water can be left on the fabric by applying controlled quantities of foam. Foam is in fact made up of 5-10% aqueous substance and about 90-95% air. Foam is generated with special devices by blowing compressed gas (usually air) in the solution containing a surfactant. The viscosity degree of the solution and gas are so adjusted to obtain air bubbles of roughly uniform diameter (50-100 μm) forming a stable and creamy foam. The foam is then deposited on the fabric in layers by means of a doctor knife. The foam, after being applied, must be settled so that the fabric can absorb the padding solution.

4. **Partial immersion systems**: a finish application roller partially immersed in a finishing liquor, rotates and touches the fabric at proper speed to obtain the application of the desired quantity of solution.This application can be controlled and optimum results can be achieved only when a precise ratio is established between the speed of the application roller and the speed of the fabric. Since the fabric speed can be modified within a wide range (it can be controlled, for example by means of moisture sensors assembled at the exit side of the dryer), the speed of the application roller must be controlled by special devices that measure the quantity of applied liquor. These measuring devices evaluate the β radiation (generated by Krypton 85) absorbed by the wet fabric. One of these measuring devices (m1) is placed before the contact point of the fabric with the application roller, while a second one (m2) measures the quantity of β radiation after the application of the finishing product.

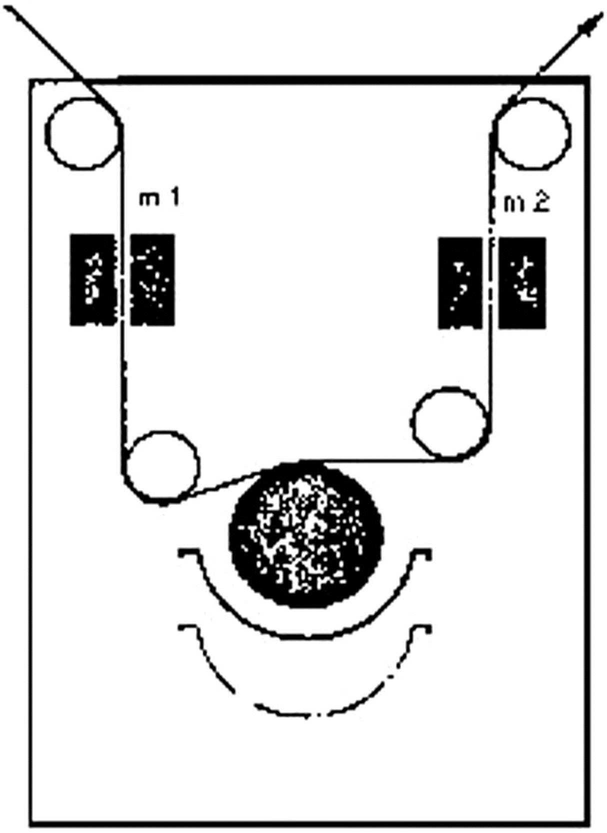


Fig. 179 Immersion system

The difference of signal between the two instruments is kept at a value corresponding to the application of the desired liquor quantity: in fact, each variation of this value determines a variation in the speed of the application roller, in order to bring the quantity of applied solution to the optimum value. For a smooth application on the fabric, a homogeneous liquid film must be created on the roller surface. This can be obtained with a special surface of the roller, but also by using the correct finishing products and auxiliaries (for example non-foaming agents.)

Softening finish

As a general rule, each fibre has its specific softness value, which depends on its chemical composition and physical structure (less crystallinity = greater softness). The fineness of the fibre or of the filament directly affects the softness of the yarn (woollens, worsteds, microfibres etc.). The yarn twist ratio is inversely proportional to its softness.
The weave also contributes to reducing (tighter woven fabric = plain weave) or increasing (looser woven fabric = sateen weave) the fabric softness. Furthermore, a greater number of yarns per centimetre increase the stiffness of the fabric, thus reducing its softness.
Softening is carried out when the softness characteristics of a certain fabric must be improved, always carefully considering the composition and properties of the substrate.
It is also worth underlining that no standard methods have been developed and established to determine exactly what the softness of a fabric is. This evaluation is therefore almost personal and carried out on the basis of operator's experience. It is anyway possible to distinguish between many types of softness:

a) surface softness,
b) surface smoothness,
c) elasticity (after compression and elongation).

To change the hand properties of a fabric, we can apply mechanical, physical, chemical or combined techniques; some of these methods (sueding, raising) have already been explained in detail in previous sections of this handbook, while some others refers to machines that give different degrees of softness, by means of high-speed rope processing in wet or dry conditions, with the drying stage carried out during the treatment (with or without softeners or enzymes.)
The functional core of these machines are the two tunnels where the fabric is fed through two Venturi tubes. The energy applied for drawing the material is produced only by air and pressure. The fabric flowing through the Venturi tubes is pushed at high speed against a grid on the machine rear side; the fabric then slides on Teflon-coated chutes and reaches the machine front side to start the cycle again; the fabric can reach a speed of 1000 m/min., depending on the type and weight of the different textiles to be processed and according to the desired results.

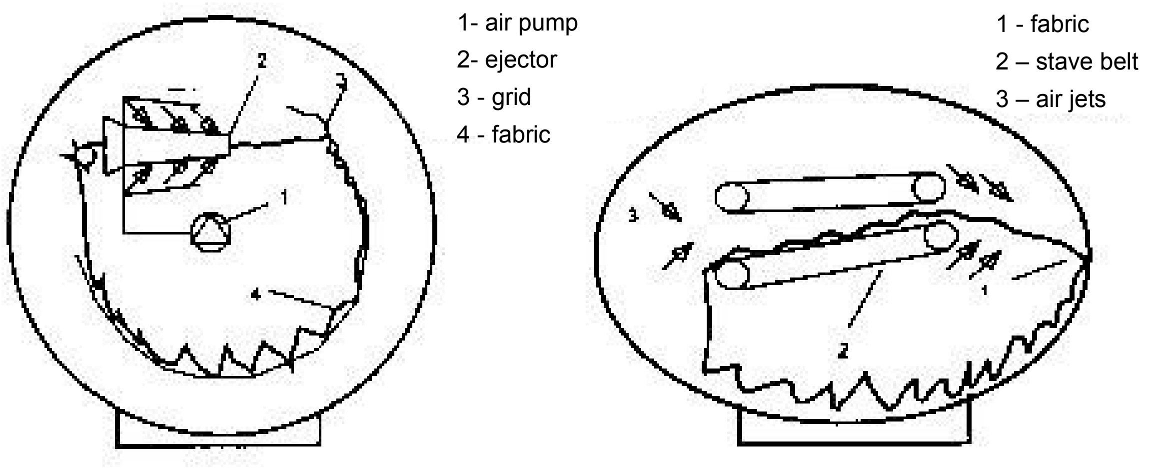


Fig. 180 Schemes of fabric softening machines

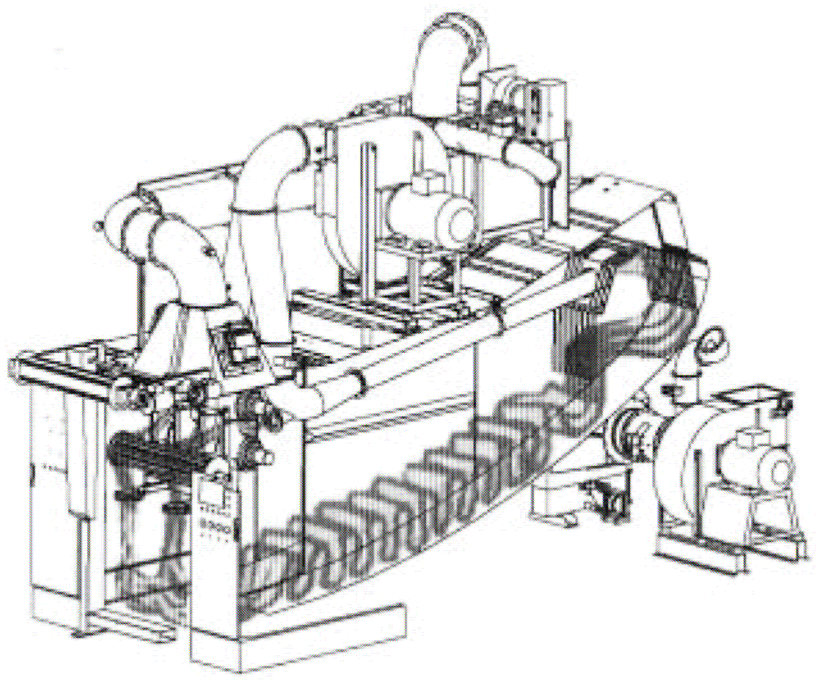


Fig.181 Scheme of a fabric softening machine

This unit applies physical and mechanical principles on fundamental elements such as:
- air, which is the fabric propeller and Scheme element;
- the mechanical stress exerted on the fabric inside the Venturi tubes and the stress due to the impact against the rear grid; -the possible action of heat.
-
- It is also worth noticing that water is not an indispensable element for the process; it is only a medium for carrying dissolved non biodegradable chemical additives (if required.)

The combination of all these elements, almost free of polluting charge, cause the structural modification of the fibres making up the fabric.

They result in more or less marked surface modifications, which can radically change the appearance and the sensorial properties of the fabrics.

The complexity of the finishing action starts inside the Venturi tube where the tail of the fabric is subjected simultaneously to a compressive action and to a subsequent series of vibrating pulses which tend to "random-modify" and compact the textile structures, eventually giving them different properties.

The one-way thrusting force is transformed into a impact force against the grid on which the fabric is pushed when emerging from the Venturi tube; this causes other modifications of the fabric and add structural and surface effects.

This simple treatment that combines physical and mechanical principles, carried out at a precise temperature set by the operator, is sufficient to create particular effects on the morphology of fibres and the weave.

The modifications produced by this treatment are very different and not only affect the colour, appearance and hand properties of the fabric, but also add new properties, e.g. modifying the refraction and diffraction of light on the fabric surface.

The most notable effects in terms of style and added value are obtained on linen, a precious delicate fibre, particularly difficult to process without using chemicals.

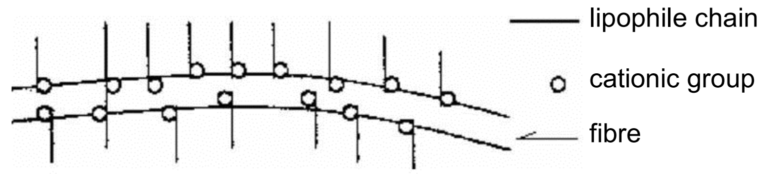
The combination of a chemical product or an enzyme liquor with the mechanical treatment can be carried out not only on linen but also on many other widely used fibres such as Tencel and polynosic fibres, imparting a draping, full and lively hand.

All these effects are obtained thanks to the air thrust and to the following impact against the grid, or to the pressure of rollers on the fabric rope.
Comparing the effects of this treatment on a Tencel fabric and on a similar treatment carried out on a dyeing machine, we can see that, as previously explained, this finishing process not only affects the appearance of the fabric, but also "cleans up" the fabric surface homogeneously, as a result providing good anti-pilling properties.
The best softness results can be obtained by carrying out the above mentioned physical-mechanical processes and by applying a special chemical softening agent.
As a general rule, the softening agents applied are hygroscopic or lubricating agents, which facilitate the fibre sliding within the fabric structure, thus granting easier deformation and creasing of the fabric. In most cases, the duration of the effect is limited since the products applied during the treatment are eliminated by subsequent washing; for this reason they must be applied in the final stage of the treatment. The most common softeners are detailed below:

Non-ionic softeners: generally ethers and polyglycol esters, oxiethylates products, paraffins and fats. These softening agents are generally less efficient than anionic and cationic ones but they withstand the effects of hard waters, acid or basic environment and also in presence of cations and anions, therefore the normal fabric care conditions.

Anionic softeners: sulphoricinates, anionic surfactants produced by the condensation of fatty acids. They have good characteristics as lubricating softening agents and give the fabric a full hand; they are unstable in hard water and acid environment. In addition, they must not cause yellowing at condensation temperatures.

Cationic surfactants: usually they are quaternary ammonium salts, amino-esters and amino-amides; they are recommended for all types of fibre, and can be also applied with exhaustion process in acid environment (pH 4-5). These are the best softening agents and are also called "molecular velveting" agents because they form bonds with the cationic group on the surface of the fibre generally with negative electric potential. They can give some problem in presence of large anions,



and they can cause dye toning, or a reduction in fastness to light values in the presence of direct and reactive dyes; they also have a high polluting charge as waste water (bactericides).

Silicone-basedsofteners: these are generally polysiloxane derivatives of low molecular weight. They are insoluble in water, and therefore must be applied on fabrics after dissolution in organic solvents, or in the form of disperse products. They feature quite good fastness to washing. They create a lubricating and moderately waterproof film on the surface and give fabrics a velvety-silky hand (desirable for velvets, upholstery fabrics and emerised fabrics)

Reactive softeners: N-methylol derivatives of superior fatty amides or urea compounds replaced with fatty acids. The products have to be cross-linked and provide permanent softness and water repellency.
As explained previously, even though some softeners can be applied with exhaustion processes on yarns, when softening fabrics, the best technique is the continuous pad-wetting process followed by a drying stage in a stenter. This treatment must be carried out at the end of the finishing process; for this reason, softening is usually performed simultaneously with other dimensional stability processes (width stabilisation, weft and warp straightening). It is worth remembering that the use of

softeners can reduce the fastness to rubbing of synthetic fibres dyed with disperse dyes, as the fatty surface layer tend to attract the dye molecules after hot treatments.

Crease-proof finishing

This chapter describes different finishing treatments as they are all carried out applying similar principles. Crease-proof treatments represent an outstanding results in finishing technology, since they give fabrics really new physical and/or chemical properties. The original aim of the researchers who first developed this process was to create a crease-proof rayon fabric; however, the new treatment was soon applied to cotton fabrics and linen cloths. The last generation versions of the treatment produce fabrics that are not only crease-proof when used but also preserve the crease effect if desired. This treatment can also ensure excellent results on cotton-synthetic blends (permanent press process.)
The auxiliaries used are synthetic thermosetting resins, or, more precisely, their monomers and their pre-condensates. The resins that react with cellulose are called "cellulose-reactants".
A certain crease resistance can be obtained by adding to fibres complex inorganic compounds of boron, as well as zinc and barium silicate. However, today the only products applied are synthetic thermosetting resins. The principle on which this finishing treatment is based consists of impregnating the fibres with resinogenic compounds of low molecular weight and cause afterward the formation of the resin in the fibres.
Recently new processes have been developed to chemically modify cellulose, aiming at improving the springback angle above all in wet substrates.
For a better understanding of what happens during a crease-proof process, it is worth explaining the mechanism and the reasons for which cellulose fibres tend to crease.
Cellulose fibres are made up of molecule chains formed by hundreds of thousands of glucose groups.

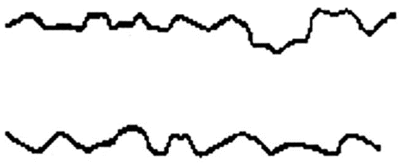


Fig. 182 Non-cross-linked polyglucose chains

Fig. 183 Polyglucose chains cross-linked with "cellulose reactants"

Fig. 184 Polyglucose chains cross-linked with thermosetting resins

The molecular chains of cellulose partly consist of crystalline areas rigidly oriented and compact, and partly of amorphous, loose and random-oriented layers; small covalence forces or electrostatic bonds cause their cohesion.
By drawing the molecular chains, a stretching effect occurs due to the breaking of weak bonds and to the subsequent sliding of the single chains over each other, a phenomenon which becomes irreversible whenever the molecular chains (and therefore the cellulose fibres) assume a new position.
If we now suppose to transfer the drawing force and therefore the stretching of the external bending of a certain point in the fibre subjected to creasing, the bending angle will assume a permanent position as a consequence of the irreversibility of the phenomenon, therefore becoming a permanent crease.
Above all, cellulose fibres rich in amorphous areas and macromolecules, which tend to form bonds in the new positions imparted by mechanical stresses, can be affected by these deformation phenomena such as stretching, creasing and wrinkling.
On the contrary, fibres like wool – whose macromolecules are fixed by strong bonds (cystinic bridges or salt bonds) – as well as fibres with highly controlled intermolecular structure and high crystallinity degree (synthetic), will be highly crease-proof. It is therefore evident and demonstrated the relationship between crystallinity, the presence of weak or

strong bonds between the chains and the crease-proof quality of the fibres. In fact, while amorphous areas facilitate the sliding of macromolecular chains, the presence of weak bonds (hydrogen bridges) allow the stabilisation of macromolecules in their new positions and therefore the formation of a permanent crease. The above mentioned hypothesis lets us suppose that the replacement of weak bonds (electrostatic) with strong bonds (covalent) – i.e. capable of reducing the displacement of the chains and bringing them back to their original position when the bending force ceases its action or when substances blocking the sliding spaces are introduced in the intra-molecular voids of cellulose – can greatly improve the crease-proof properties of fibres. These pre-conditions are partly ensured by the so-called "amino-plasts", as well as by cellulose reactants, which can form large-size molecules of resins, or bridges between the individual cellulose molecular chains, respectively.

Before the drying stage, fabrics are impregnated with precondensed amino-plasts of low molecular weight, or with cellulose reactant solutions. Before the 1990s, these solutions consisted of N,N-l.3dimethylol-4.5-dihydroxyethylenurea (DMDHEU) combined with magnesium chloride as acid catalyst, to improve the formation of cross-linking bonds between the molecules of cellulose chains. The development of these bonds inside the amorphous areas of the fibre, improves the resistance to distortion and enhances elasticity properties; unfortunately the chemistry of N-hydroxymethyl (N-methylol) derivatives has a great drawback due to the reaction: $-H_2NCONH_2$ + HCHO, which produces free formaldehyde.

In fact, during the subsequent hot treatment which favours the formation of the resin, a bond with an hydroxyl of the cellulose ring sets individually, leaving an N-hydroxylmethyl group non reacted and capable, following an hydrolysis process, of releasing formaldehyde, above all at high temperatures.

Another problem occurring when using these resins is represented by the chlorine absorbed by the textile material during the washing process, which cause a visible yellowing of the textile surface.

This does not represent an immediate damage, but when the textile is subjected to the action of heat (ironing, calendering, steaming) it also loses a considerable part of its mechanical resistance.

Properties of various resins Dimethylol-urea

dimethylol-urea DMU	dimethylol-ethylene-urea DMEU	dimethylol-dihydroxyl -ethylene-urea $DM(OH)_2EU$	dimethylol-dihydroxyl -ethylene-urea $DM(OR)_2EU$	dimethylol-dihydroxyl -ethylene-urea $Dimethyl(OR)_2EU$
non reactive	good reactivity	good reactivity	medium reactivity	medium/low reactivity
easily hydrolysab	stable to washing	stable to washing	highly stable to washing	sensible to hydrolysis
high chlorine retention	medium chlorine retention	medium chlorine retention	low chlorine retention	no chlorine retention
easily dry condensable	cross-linkable in dry and humid conditions	cross-linkable in dry, humid and wet conditions	cross-linkable in dry and humid conditions	only applicable by dry condensation
poor stability of treatment liquors	negative influence on fastness to light	no influence on fastness to light	low influence on hand properties	tendency to yellowing
high formaldehyde content	high formaldehyde content	medium formaldehyde content	low formaldehyde content	no formaldehyde content

Application techniques

Today, a number of treatments are available to give excellent properties to a wide range of textile products. The "wash-and-wear" finish is particularly effective since treated fabrics not only lose the creases formed on the dry fabric (i.e. when used) but also the creases which form on the wet fabric during manual or machine washing. The treatment to eliminate post-finishing creases is more complicated that the crease-proof treatment.

The cross-linking process can be carried out in three different ways:

1. **dry method**: with this method it is possible to obtain wide springback angles for dry creases and only medium springback angles for humid creases; dimensional stability and shape retention are excellent. The tearing and abrasion resistance loss is proportional to the dry crease angle, and are therefore generally high;
2. **humid method**: the springback angles for humid creases are usually wide (proportional to residual moisture content), and dry ones are also good. Good dimensional stability and no-ironing properties (i.e. no ironing is required after washing). Low loss of tearing and abrasion resistance;
3. **wet method:** optimum springback angles for humid creases, but very limited for dry creases. Good no-ironing properties and dimensional stability, with very low loss of tearing and abrasion resistance.

1 – Dry method

The classic method: the fabric is impregnated by means of a padding unit (the quantity of finish is tuned by modifying the liquor concentration and the squeezing ratio) and dried at 100-120 °C in a stenter; the cross-linking process occurs in the stenter, at temperatures varying according to the type of cross-linking agent used (generally 4-5 minutes at 150-160 °C). At the end of the process it is recommended to carry out a washing and softening stage (see STK process). Both self-cross-linking and reactive products can be used; ammonium salts or complex compounds are used as catalysts. It is a simple and quick process, as well as one of the most cost-effective. STK: drying and condensation are carried out simultaneously in a single run in the stenter at high temperatures (140 °C at the entry side, 180 °C at the exit side). The dwelling time inside the stenter depends on the products and the catalysts used, the temperature, and the substrate. This method is really cost-efficient but its results are quite uncertain and deterioration of the textile material may occur during the dwelling time in the stenter due to the high operating temperatures (resulting from the moisture variation in the fabric). For these reasons, STK is used above all for viscose. This process still requires a washing cycle to be carried out in order to comply with the strict regulations on formaldehyde fumes and the release of the metals contained in the catalysts.
Double treatment: the fabric is impregnated with a softener and dried at 100- 130 °C. The procedure applied is the same as with the STK process. The application of softeners before the cross-linking or reactive agents provides excellent crease-proof properties and a limited loss of tearing and abrasion resistance. Permanent-press: the cross-linking step is carried out by the operator and gives good crease-proof properties and dimensional stability, and is therefore used to ensure shape retention for the finished garment. Two operating methods can be applied:
Post-curing: the fabric is impregnated with a solution of scarcely reactive cross-linking agents and special strong catalysts. Then the fabric is dried at low temperature and sent to the maker-up for cutting and ultimate making-up operations. Then it is hot pressed to assume the final shape and simultaneously obtain the cross-linking effect. (This method is scarcely applied due to the problem of formaldehyde fumes released and by non-washed fabrics or during storage.)

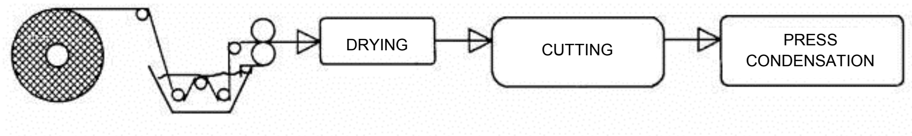


Fig. 185 Dry permanent press cross-linking process with post-curing method

Post-curing for blended fabrics: used for fabrics containing at least 55% of synthetic fibres. The fabric is impregnated, dried, condensed and washed for stabilisation, to give a crease-proof properties to cellulose fibres and eliminate the free formaldehyde. After the cutting and making-up stage, a high temperature pressing stage will impart the final shape to the finished garment by exploiting the thermoplastic features of synthetic fibres.

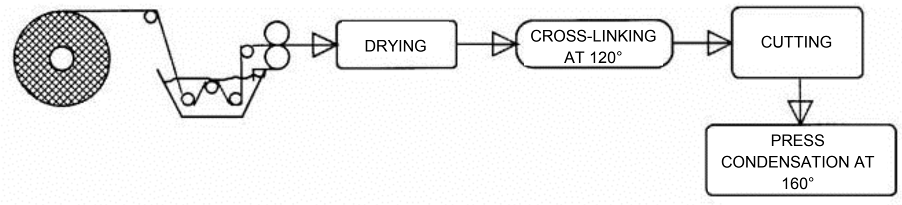


Fig. 186 Dry permanent press cross-linking process with post-curing system for blended fabrics

The same method can be used on fabrics made of cellulose fibres only, using a combination of two cross-linking agents with markedly differentiated reactivity values as a wetting agent (see figure). A first cross-linking step is be carried out on the fabric at low temperature (120-140 °C), while in the subsequent high-temperature pressing step (160-180 °C) the less reactive cross-linking agent will condense to set ultimate shape. (See the section on the post-curing method as far as formaldehyde is concerned.)

2 – Humid method

The fabric is wetted by means of a padding unit with a cross-linking agent and a catalyst solution; then 6-8% of residual moisture is removed from cotton (or 10-15% from other staple goods.) The fabric is then wound up on a roll, covered with a polyethylene sheet and left 16-24 hours to rest at ambient temperature. Strong catalysts must be used for this process and their quantity is tuned according to the residual moisture content. The final effect depends on the residual moisture: in case of low residual moisture content, the results will be similar to those obtained with the dry process whereas if the residual moisture content is high, the result is very similar to the cross-linking effect on wet substrates. The fabric hand after the treatment is generally soft. The fabric is then washed, the acids neutralised and the fabric is finally softened. Obviously this method does not allow continuous processing techniques, and therefore is not as common as dry cross-linking. However it ensures excellent results in wash-and-wear treatments, with low loss of resistance.

3 – Wet method

This method can be carried out in acid or alkaline environment. (The latter is less common as it gives limited crease-proof properties, though very low loss of tearing and abrasion resistance.) This method is similar to the previous one, except for the drying stage. The material is dried, wrapped, wound and covered with polyethylene and it is then kept rotating for 16-24 hours. The percentage of absorbed liquor vary considerably according to the type of processed fibres: Cotton: R.S. 100%, Polynosic: R.S. 120%, Staple: R.S. 200%.

Flameproof finishing

The term inflammability refers to the ease of ignition and burning rate of fabrics. The flammability of fabrics (particularly drapery, textile covering and clothing fabrics) constitutes a danger in ordinary conditions of use.

L.O.I. of the main textile fibres	
Textile fibre	*L.O.I. (%)*
Wool	25
Cotton	18
Viscose	20
Acetate	18
Triacetate	18
Chlorofibres	48
Acrylic	18 – 20
Modacrylic	22 – 28
Polyester	20
Polyamide	20

The flame response of textile fibres is linked to their L.O.I. (limit oxygen index), which indicates the minimum quantity of oxygen a fibre needs in order to burn.
Given that the percentage of oxygen in the air is around 21%, it is clear that all fibres with a L.O.I. lower than this level will burn easily, while those with a higher L.O.I. will tend not to burn. From the table it can be seen that polyester, polyamide – both of these melt and form viscous masses – and cellulosic fibres are highly flammable. The latter, especially in less compact fabrics in which they have greater contact with the oxygen in the air, burn rapidly if heated to around 350°C, temperatures at which they break down into highly inflammable volatile substances and carbonaceous residue.

The combustion mechanism and flame-retardant treatments

Cellulose exposed to high temperatures breaks down into flammable substances. Combustion of these products generates further heat, causing the cellulose degradation and breakdown process to continue until the cellulose has entirely disintegrated.
Cellulose combustion is a process that occurs in stages:

1) *Pyrolysis*: the action of an external heat energy source causes the homogeneous breakdown of the cellulose into liquid gas, tarry and solid products. The temperature at which rapid pyrolysis is triggered is around 300°C.

2) *Combustion of the produced gases*: at around 350°C the flammable vapours produced in the previous stage ignite, giving rise to a strongly exothermal oxidation reaction, which produces volatilisation, further pyrolysis and combustion of the liquid and tarry substances formed previously. From this point on, combustion proceeds spontaneously, resulting in the release of considerable heat, until such time as the cellulose material is completely burned up.

3) *Post-combustion*: when the tarry liquids produced in the first stage of combustion have undergone pyrolysis and combustion, a carbonaceous residue remains that undergoes slow oxidation (also exothermal) and continues to glow until it has been completely burned up.

To sum up, a fabric undergoing combustion will present the following zones:

a) a zone in which there are no longer any flames in evidence and in which combustion residue (ash) is present;
b) a carbonaceous zone, glowing but flame-free;
c) a burning zone: it is here that the violent oxidation of the gases produced (a series of reactions) is taking place;
d) a zone in which it is possible to observe initial carbonisation and where the cellulose is undergoing the reactions of pyrolysis;
e) an intact zone.

Theory of flame retardant systems

The action of flame retardants on cellulosic fibres can be explained in several ways:

1) *Through formation of non combustible gases*, a result of the action of the heat on the flame-retardant product that has been added. These gases act in two ways: they reduce the concentration of combustible volatile substances, and they reduce the concentration of oxygen needed in order for the combustion process to continue. In decreasing order of efficacy, they act on the following gases: NH_3, HI, HBr, SO_2, CO_2, H_2O, and N_2. To achieve this end, the following substances are used: ammonium salts and organic nitrogenous compounds, like amine; b) organic halogenated compounds; c) salts containing high quantities of crystallisation water.

2) *Through catalytic action on cellulose dehydration*, in such a way as to obtain, at temperatures lower than ignition temperatures, a carbonaceous residue and to reduce the formation of flammable gases. This dehydration is catalysed by the acids.

3) *Through products preventing formation of anhydroglucopyranosium*. Since it is known that one stage in the pyrolysis of cellulose is the formation of levoglucosone, one need only block the hydroxyl groups in position 6 on the glucose molecule in order to reduce considerably the formation of flammable pyrolysis products. This objective is achieved by replacing the alcoholic function with the $–O\text{-}SO_2\text{-}CH_3$ group, with bromine, or by making the hydroxyl react with nitrogenous compounds.

4) *Through the catalytic action of the derivatives of phosphorus* (phosphoric esters). These compounds reduce or prevent post-combustion of the carbonaceous residue. In the presence of phosphoric esters, the following reaction is favoured: $C + 1/2\ O_2 \rightarrow CO + 26.4$ Kcal, which is weakly exothermal in relation to the much more strongly exothermal reaction (94 Kcal) that leads to the production of CO_2. As a result, the temperatures reached in this case are low and the post-glowing phenomenon is absent. To achieve this objective, the following substances are used: ammonium phosphates, blends of phosphoric acid and amines, organic compounds containing phosphorous and ammonium.

5) *Through catalytic action inhibiting the oxidation of combustible gases.* Oxidation in the vapour phase is a process involving free radicals, some of the most important of which are the free radicals of H·, OH· and O·. The flame quenching action is often attributed to the capacity of the added substances to capture these radicals.

The action of bromine compounds, for example, is shown in the following scheme:

$$RBr + H^\circ \rightarrow HBr + R^\circ$$

If the $R^{\cdot}$ radical that is formed is less active than the $H^{\cdot}$ radical, the result is inhibition of oxidation. In general, removal of the H°, OH° and similar radicals by other less active radicals results in suffocation of the flame.
This is similar to the action of antimonium halides, compounds that are very efficient at capturing free radicals.

The main products used in flame retardant treatments of cellulosic fibres

Soluble inorganic products: ammonium salts, such as chloride, bromide and phosphate, applied in concentrations ranging from 10-20%, are very widely used. Borax, too, applied in concentrations of 6-10% and blended with boric acid (ratio 7:3) also confers good flame-retardant properties.

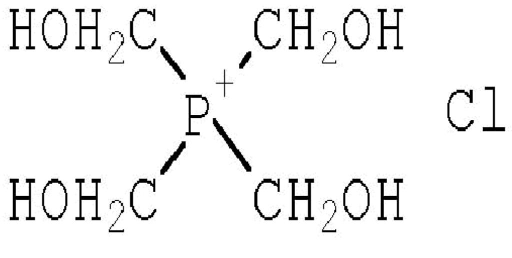
Soluble organic products: the substances used include ammonium sulphamate, phosphates, dicyandiamide, and thiourea.

Water-repellent treatments: these treatments are also relatively resistant to domestic washing and dry cleaning. They include the *Perkin treatment* (based on the deposition of stannum hydroxide). The cellulosic fabric is padded with sodium stannate, dried, treated with ammonium sulphate and dried again.

Treatment based on phosphoric acid and nitrogenous compounds: phosphoric acid, bound to the cellulose's hydroxyl group, has good flame retardant properties, however it reduces considerably the mechanical strength of the cellulose itself. To reduce degradation damage and improve flame retardancy, bases, like the ones listed here, are added: urea, guanidine, melamine, dicyandiamide, and nitrogenous resins such as urea-formaldehyde, melamine- formaldehyde (the latter also increase the solidity to washing of the product). A further improvement is obtained using phosphoric acid condensation products with the above-mentioned amines.
Of the various procedures proposed, the Bancroft procedure renders the flame-retardant property permanent to a degree. It consists of treating the cellulosic fabric with aqueous solutions of phosphoric acid-urea pre-condensate, applied by means of padding. This is followed by drying and by a thermal treatment. The latter, carried out at temperatures ranging from 140°C to 160°C enhances the condensation of phosphoric acid and urea and also fixes the condensate on the fibre as a nitrogenous phosphoric ester of the cellulose. The fabric is then washed thoroughly and dried. This flame-retardant product, which has low solidity to domestic washing, severely reduces the strength of the fabric and sometimes results in a change of colour.
The treated fabric has good hand properties.

Permanent salt- or metallic oxide-based products: these derive from the union of metallic oxides with organic substances that are thermally unstable and have a high chlorine content (40-75%).
The metallic oxides can be: antimonium, arsenic, lead, zinc and stannum oxides, while the organic substances can be polymers of vinyl chloride, vinyldiene chloride, chloroparaffin. The effect is lasting. This treatment is widely applied the USA, where it is known as "F.W.W.M.R. Finish" (i.e., flame, water, weather and mildew resistant).
Antimonium trioxide (Sb_20_3) offers little flame retardancy, unlike oxychloride and trichloride; the latter, however, through hydrolysis, release hydrochloric acid on fabrics, and this attacks the fibres.

Phosphorous-based products: in this family of compounds, tetrakis hydroxymethylol phosphorium (THPC) stands out in particular. Being without elements able to form non combustible gases, it is not used alone but rather with other flame-retardant products containing nitrogen or halogens (such as the azydirinic derivative APO) or with nitrogen compounds such as trimethylolmelamine or ureic resins with which it copolymerises.



THPC

A process that has a particularly important application is the Proban process. This process exploits the copolymerisation of THPC and methylolmelamine to form a highly flame-repellent resin that contains phosphorous and nitrogen. The two products are dissolved in the same liquor to which triethanolamines are added as stabilising agents and urea as a buffer agent. The effect is permanent and, provided there is not too much alkali present, not affected either by domestic or industrial washing. The most difficult part of the application of this treatment is the final polycondensation, which demands well ventilated equipment and perfectly controlled treatment times, otherwise the mechanical strength of the fabric is severely jeopardised.

THPC-urea process (or process with melamine, dicyandiamide or guanidine). The fabric is impregnated with THPC and one of the above-mentioned nitrogenous substances, after which it undergoes a thermal treatment. It is dried, treated with ammonia, rinsed and dried again. A good and wash-resistant effect is obtained.

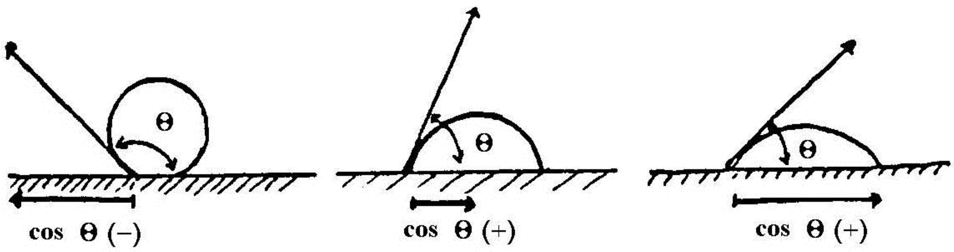
Hydrophobic, oil-proof and water-proof finishing

Waterproofing is a treatment that does not allow water or air passing through the fabric. It consists of the application of substances capable of forming a thin waterproof layer, eliminating any space between the fibres and yarns in the fabric.
The hydrophobic treatment gives the fibre the ability to repel water, but not air and water vapour. This treatment does not clog the fabric pores but reduces the capillarity effect by coating the textile substrate with substances having a low surface tension.
The stain-proof treatment makes the fabrics hydrophobic (thus avoiding aqueous substances to penetrate them) and oil-proof (which limits or prevents the penetration of fatty substances).

Wetting of the textile substrate

We will now try to explain why a textile surface becomes wet. The natural hydrophilic characteristics of fibres greatly facilitates all finishing processes, and dyeing in particular, but this property can represent a problem under certain conditions, e.g. soiling caused by water or oil soluble substances, or when protecting a person during outdoor work or even when the fabric must withstand harsh weather conditions.
It is therefore important to get a better understanding of these phenomena to improve the water and oil repellency of textile substrates, above all when they are destined to special uses (for example working garments.)
Since it is impossible to modify the basic chemical structure of fibres or eliminate the porosity typical of textile products, it is important to modify surface and chemical structures.
The wetting of a textile substrate produces a three-phase modification (solid, wetting fluid, air), generating simultaneously surface and interfacial tensions.
Let's imagine a drop of liquid substance deposited on a solid surface: the attraction forces between its molecules allow the drop to keep its spherical shape.
If great attraction forces generate from the solid surface in contact with the liquid (i.e. in case that the solid has a great surface energy), the surface tension of the liquid is not sufficient to keep the spherical shape: the drop consequently spreads on the surface and becomes more similar to a flat lens. Then it adheres to the surface and wets it.
To cause the surface of a solid not to be wetted by a liquid, the surface energy of the solid must be inferior to the surface tension of the liquid.
A liquid therefore adheres to a solid because of the attraction forces originating from the molecules of the surface of the liquid and of the solid (interfacial tension) and is independent from the underlying molecular layers.

Wetting can be evaluated by measuring the contact angle formed by the intersection of the surface of the solid and the tangent of the arc surface of the drop. This angle is indicated with the symbol θ (theta).



Therefore:
If the surface can be wet, we shall have θ < 90° and 0 <cos θ < 1;
If the surface is scarcely wettable, we shall have θ > 90° and -1 <cos θ < 0.

Since the tendency of the liquid to wet a solid is inversely proportional to the contact angle, cos θ becomes a direct measure of the wetting property.

Wettability and penetration of a liquid through a fabric

Along with the above mentioned criteria, it will be worth considering that the surface of the fabric is more or less rough and therefore greater than its apparent surface. The value of cos θ (which expresses the wetting ability) must be therefore multiplied by the roughness factor "r" (with r > 1), and therefore the tendency of the fabric to wet becomes proportional to r cos θ .
This relationship shows that if a smooth surface can be excellently wetted, its roughness will improve its wetting ability while if a smooth surface can be wetted with difficulty, its roughness will render it even less wettable.
The diameter and the distance between the yarns of a fabric are also very important and must be carefully evaluated in waterproof and oil-proof applications.

On a perforated surface like that of a fabric, liquids form contact angles which increase in proportion with the ratio r + (d / r) (Cassie and Baxter relation) where:
"r" is the yarn diameter,
"d" is the distance between two fabric threads.
Furthermore, the liquid in contact with a porous solid like a fabric, tends to penetrate it like a capillary fringe, up to a height (h) depending upon the surface tension of the liquid (γL), its density (ρ), the radius (r) of the capillary fringe and the angle of contact (θ) between the liquid and the solid:
$h = K \gamma L \cos \theta / r \rho$

Therefore, when the angle of contact is smaller than 90° (cos θ> 0) the liquid will show a capillary diffusion into the solid.
Once the liquid has penetrated the fabric, the surface tension of the liquid no longer contrasts the flowing of the liquid and a stable flow will establish. Generally speaking, a fabric that has been made water repellent can better stand wetting and water penetration if yarns are small and the weave is thick.

Hysteresis of the angle of contact

The angle of contact (θ) reduces by increasing the contact between the liquid and the solid. It is therefore necessary to underline the difference between: the advancing angle (formed by a drop in contact with a dry surface) and the receding angle (formed on a surface previously in contact with the liquid).

The difference between these two values is the hysteresis of the angle of contact. The higher the hysteresis, the poorer the tendency of the liquid to "pearl" (i.e. to slip on the surface of the fabric by forming separated droplets), notwithstanding the high advancing angle. This is an important factor to be considered, for example in materials that will be exposed to rain and on which, after a certain period of time, the pearling effect no longer occurs. The hysteresis of the angle of contact is higher when the fabric is wet with water than with organic liquids. A specific material after the flame retardant treatment must have high receding angles (at least >90°).

Porous solids, like textile substrates, have a water receding angle that decreases very rapidly according to the period of immersion. For example, the pearling effect will disappear and water will form a continuous surface film if a fabric is exposed to the rain action for a certain period of time.

The supremacy of silicones compared to other waterproofing agents is due to the slow decrease of the receding angle rather than to a high angle of contact.

In case of surface contact between the fabric and water, the hysteresis of the contact angle can be originated by different reasons:

- formation of a hydrous layer on the surface of the solid, due to water or water vapour absorption;
- solubilisation in water of part of the hydrophobic substances (or mechanic removal),
- the breaking of an hydrophobic film and the subsequent fibre hydration,
- orientation inversion of the hydrophobic film, which (in contact with water) directs polar groups towards the surface.

Hydrophobic treatments and products

For the above mentioned reasons, to avoid the wetting of the surface of a macromolecular and porous material like a fibre, the surface must be covered with a film formed by a substance with a surface tension that is smaller than the textile.

In this way the drops of water will assemble on the surface, isolated from each other, to create the pearl effect.

A waterproof effect can be also obtained by using non-filmogenic substances that form a sort of "brush" of short molecules. By limiting the formation of a hydrophobic state on the surface of the textile substrate, the basic properties of mechanic resistance and flexibility of the fibres remain unaltered. If also swelling (mainly due to the presence of amorphous areas) must be strictly controlled, these amorphous areas can be filled with macromolecular resins.

Both polymer and low chain water-repellent products should have essentially a hydrocarbon character (with groups having a lower surface tension such as $=CH_2$, $-CH_3$ or perfluorinated chains), to reduce the surface tension of the fibre until making it water-repellent.

Method based on emulsions in single bath

This method is recommended for producing awnings or camping tents and umbrellas but it does not stand washing in water and solvents. The size of the emulsion particles must range within 0.1 and 2 micron, and can be stabilised, or not, by using protective colloids (hide glue, cellulose ethers, polyvinyl alcohols). The textile substrate treated with this method is dried in stenters at 80-100°C. Good results can be obtained with medium-weight/light fabrics made of cotton, cotton-synthetic blends and wool, with a good cost-efficiency ratio. Unfortunately the waterproof finish is not a durable one. Better results for waterproof ability and solidity to usage and washing can be obtained by replacing Al salts with Zr salts (ammonium and zirconium dicarbonate, zirconium oxychloride, etc.), by applying them on fabrics made of cotton, cotton-synthetic blends and wool, with a technique similar to the above mentioned one. Good results can also be obtained on cotton, blends and wool, by using chromic chloride stearate emulsions with or without colloids, in presence of examethylene tetramine, by padding the fabric, drying it and polymerising at 130°C for 3 minutes.

Durable methods

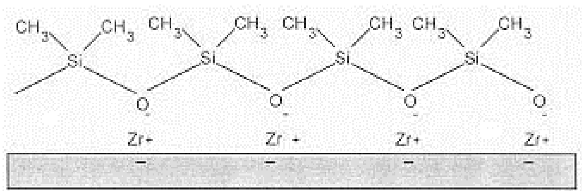
It is possible to bind hydrophobic chains to cellulose fibres by reacting the primary hydroxyl groups (etherification, esterification, etc.); the waterproof values reached are generally poor, but durable, since they do not cause the formation of the surface film.
The results can be remarkably improved when these products are combined with resins.
Usually the fabric is wetted by dispersing the product; the fabric is then dried and treated at 90-120°C.

Products made of resins linked to fatty acids

These products feature excellent solidity when washed in water at 60-90°C, though not when washed with solvents. They are recommended for treating raincoats, uniforms etc. It is possible to use methylol-ureastearamide derivatives, ether alcohols superior to dimethylolurea, but more frequently melamine derivatives linked in different ways with lipophile chains. These products (whatever their formulation) can be used for padding applications in the presence of acid catalysts (ammonium chloride, ammonium nitrate, aluminium chloride or zirconium oxychloride), dried and polycondensed at 140-150°C. It is important that fabrics made of synthetic fibres dyed with dispersed dyes, are dried at low temperatures after the padding process; this prevents the dyes from migrating toward the hydrophobic surface and maintains the fabric's solidity to rubbing.

Silicone-based products

These products are stable to washing in water at 60°C and with solvents. They can be used to treat uniforms, raincoats and sportswear. These products are very popular since they allow excellent waterproofing properties, optimum solidity (that can also be enhanced if combined with resins) and a very pleasant and soft hand (they are also used as softening agents.)
Starting from silicon and chloromethane, or from silicon tetrachloride with Grignard reagent, they are made react with water to release silanols.
The dymethylesilanols obtained in this way can polycondensate in acid environment by forming linear dimethylpolysiloxanes.
Precondensed products with low molecular weight are generally available on the market as solutions (in organic solvents such as carbon tetrachloride or n-decane) or contained in aqueous emulsions; they are recommended for completing the condensation process on fibres at 140-160% or in milder solutions for longer times (acid hydrolysis of cellulose is avoided with a loss of tenacity) by adding special catalysts (Zr oxychloride and Zn nitrate).
They are suitable to be applied on all types of fibres and also on emerised or coated fabrics. The high water-repellent effect and the soft hand are due to the orientation toward the outer surface of methyl groups induced by positive Zr ions linked to the negatively charged fibres:



fibres

Fluoride-based products

They feature an excellent fastness to washing in water and solvents. They are suitable for treating uniforms, raincoats and sportswear, tablecloths and protection clothes (after washing they must be ironed to recover their original effect).
These products are resins bound with hydrocarbons having at least the last four atoms of C perfluorinates.
These products allow excellent waterproofing results also with oil-repellency properties (if stains have not been pressed onto the fabric.)
The application is carried out by padding the fabric, which is then dried at 100-120°C and subsequently polymerised at 140-150°C.

Stain-proofing treatment

This treatment is often combined with waterproofing and other finishing treatments, and is particularly indicated for synthetic fabrics (oil-wettable) and synthetic blends, but it can also be carried out on all types of fibres.
The stain-proof treatment bases on the application of molecules having hydrocarbon chains of at least 4 atoms of perfluorinated carbons, included the last one. These chains must be homogeneously distributed on the surface of the fibres and must represent at least 1% of the weight of the textile substrate. The most commonly used products are based on perfluorinated esters resins of acrylic acid and/or perfluorinated esters of polyvinyl acid, which make the fabric hardly wettable with oily and aqueous fluids. Furthermore the presence of fluorocompounds makes it easier to remove oily stains with solvents, by shrinking the stained area and avoiding the formation of halos.

Rf = Perfluorinated chain

Soil-repellent finishing

Hydrophilic fibres (both natural and man-made), when non-treated, are considered easy-wash materials, which, moreover, do not absorb dirt during washing. This is to be attributed to the fact that they have a very high critical surface tension in air, and thus a very low interfacial tension in water. On the other hand, certain synthetic fibres (particularly polyester), like cellulose fibres that have undergone chemical finishing processes (based on silicones, fluorocarbon compounds, permanent-press or wash-and-wear resins and acrylic resins), are difficult to clean because of their highly water-repellent surfaces. These surfaces produce an accumulation of electrostatic charges, and thus absorb and retain dirt.
Clearly, therefore, there is a need for treatments that reduce the natural build-up of dirt with use - a treatment that is applicable to any fabric and that allows it:

1. to repel dirt during use (i.e., that makes it soil and stain repellent);
2. to be cleaned easily through normal cleaning procedures (brushing in the case of carpets, washing in the case of shirts, etc.) (i.e., that confers soil-release, easy-wash properties);
3. not to take on, during washing, that greyish/yellowish hue that is due to the re-depositing of soil particles from the dirty water (anti-soil redeposition).

There is no type of finishing treatment that can confer, at the same time, all these properties on a fabric. Indeed, in some cases, a finishing treatment that confers one of the aforementioned properties, reduces the performance of the fabric where the others are concerned. Thus, the choice of an anti-soil treatment must be governed by the extent to which the article is effectively likely to become soiled – and this of course depends on its destined use.
For the sake of simplicity, the substances liable to soil a fabric can be subdivided as follows:

- solid particles. The fabric will occasionally come into contact with fine particles capable of soiling it (soot, rust, blends of organic and inorganic substances).
- oils and greasy substances;
- water-soluble substances (natural colorants present in products such as coffee, wine and ink).

There are five different ways in which these substances can come into contact with the fabric:

1) through direct transfer (contact);
2) through the deposition of airborne substances (solid particles that, because of their density, fall onto the fabric or that, because of its electrostatic charges, are attracted to it);
3) through the deposition of substances contained in solutions or aqueous suspensions (solid particles, for example mud particles, or particles present in oily or coloured liquids). This category also includes the dirt contained in dirty washing liquor, which, despite being extremely diluted, can redeposit extremely fine soil particles deep within the fibre. Furthermore the high temperature of the liquor can favour the penetration of certain soil particles and even fix others in the fibre;
4) through transportation via oils and greases (greasy substances, but also solid transported substances, such as those present in lubricants, or coloured substances, like those contained in lipsticks);
5) through deposition of substances contained in solvents. Garments washed using dirty solvents can retain the soil particles they contain.

Fibres can retain solid substances (dirt) in a number of ways:

- by macro-occlusion or the trapping of particles between threads or fibres.
- by micro-occlusion of the smallest particles in irregularities present on the fibre surface. Since the size of these irregularities is below 50 µm, only soil particles of a similar size are trapped.
- by absorption at the level of the fibre surface, due to Van der Waals and Coulomb forces.
- by solubilisation or absorption of oily substances deposited on the fibre. This is associated, above all, with synthetic fibres.
  - by bonding to the finishing agent on the fibre, especially plastic or soft resins.
  -

The ease with which dirt is eliminated or absorbed is influenced considerably by the geometry of the fibre and yarn. Indeed,

- round-section fibres soil less and come cleaner during washing;
- curly staple fibres, with an irregular section have an increased tendency to absorb and retain dirt;
- dirt easily penetrates – but is also easy to eliminate from – yarns that are loosely twisted, whereas the dirt that penetrates more tightly twisted yarns is more difficult to remove;
- very highly twisted yarns show very little susceptibility to the penetration of dirt.

Pre-soil treatment

Solid particles of dirt are deposited on fibres, adhering mechanically to their rough surfaces: those involved in the first stage of fabric soiling find their way into the pores, producing a colour that is very difficult to get rid of; on the other hand, those that are absorbed subsequently (i.e., once the fibres' pores are full) can be eliminated through simple mechanical actions.
If, therefore, a finishing treatment is used that fills in the fibre's surface irregularities (pores, indentations, holes) with white and translucent particles, the dirt that is subsequently deposited will inevitably adhere only superficially and thus be removable through the application of normal cleaning techniques (brushing, vacuum cleaning).
However, the diameter of these "pre-soil" material particles must correspond to that (0.05-0.2 micron) of the irregularities present in the fibre, as larger particles would afford only temporary protection.
Of the products that have been applied in practice, particularly in the treatment of carpets, some, in particular, have given successful and durable results. These include: oxide blends, such as zinc aluminium, magnesium, iron, and aluminium phosphate blends, all applied by means of sprays, padding or exhaust processes. The disadvantages of this treatment are
uncontrollable dust formation and, if a continuous film forms, a hardening and worsening of the hand.

Soil Release treatment

The expression "Soil Release" refers to the capacity to release dirt through wet cleaning. The aim of this finishing treatment is not to prevent a textile from soiling, or to reduce its tendency to absorb dirt, but rather to facilitate the removal of dirt through wet cleaning.
Soil Release finishing treatments are used, in particular, in the polyester curtain sector and in the production of other textiles destined to be made up into household linen or underwear. While Soil Release finishing treatments are only rarely applied to polyamide or acrylic fibres, they are more often used on blended goods (wool/acrylic fibres), destined to be made up into items of women's clothing.
The Soil-Release finishing treatment is based on a process that enhances the hydrophilic properties of the fibres in such a way that the dirt, particularly water-repellent dirt, passes more easily into the water during domestic washing cycles. The figure below illustrates, in this regard, the relationship that is established between dirt and detergent during wet cleaning: the longest part of the detergent molecule (the hydrophobic, unipolar part) becomes oriented towards the dirt, while the hydrophilic (polar) part remains free in the aqueous medium.

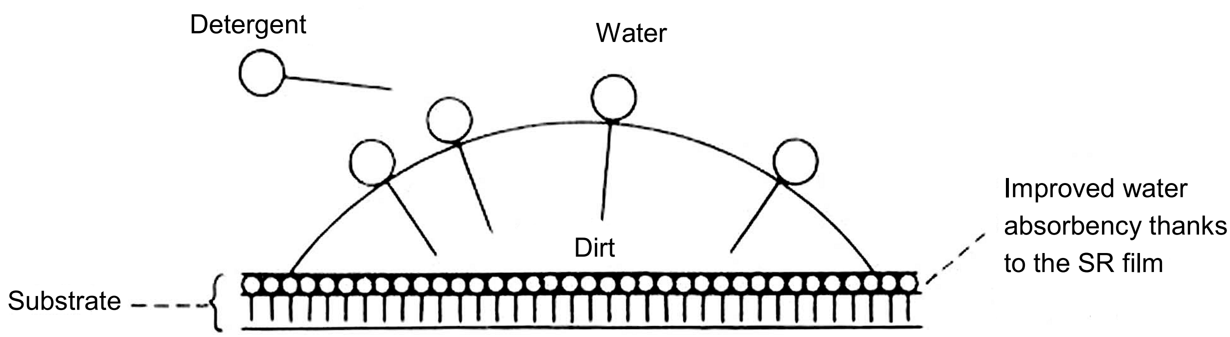


Fig. 187 Scheme of the effect resulting from Soil Release treatment

As shown in the diagram, the Soil Release effect is obtained through the use of a chemical that has the capacity to form, on the surface of a fabric, a film (SR) that is able to reduce the attraction of the dirt towards the hydrophilic surface of the textile and, at the same time, to facilitate the introduction of the washing liquor between the dirt and the surface of the textile.
The chemical products found to be best suited for this particular use are ones that have the capacity to form a thin film – that is not sticky and that does not present plastic properties in the presence of heat – of negative charges on the surface of the fabric.
What is more, these products are able to confer an anti-static effect, which also favours the release of soil: the accumulation of electrostatic charges is, indeed, one of the main reasons why airborne particles are retained by synthetic fibres (the latter, through electrostatic mechanisms, attract them and bind them to the fabric).
These products are emulsions, based on polymers or copolymers of acrylic or metacrylic acids, or on the relative salts, as well as on additional ethylene oxide compounds, and fluoride compounds. All are particularly resistant to wet cleaning, providing a metallic salt catalyst is used in the application stage.

Anti-static treatment

Being characteristically hydrophobic, synthetic fibres present a low electrical conductivity, so low that, after rubbing against other bodies, they can retain an electrical charge for a long time.
Indeed, when two bodies, characterised by a neutral electrical charge and each having a different chemical composition, are rubbed together, the electrons of each of them will attract those of the other in such a way that both bodies acquire an electrical charge.
Generally speaking, the body with the higher dielectric constant takes a positive charge, while the substance with the lower dielectric constant takes a negative one.
A potential difference, of as much as several hundred millivolts, is created between the two contact surfaces.
If these two bodies, both charged with electrical energy, are separated, the potential is increased, even as high as many tens of thousands of volts.
As far as fabrics are concerned, this discharge of energy occurs mainly between the innumerable fibrils. It is responsible for creating the familiar crackling sound and for the formation of the tiny sparks and the genuine electrical discharges that can cause perceptible discomfort. To reduce this phenomenon, one can operate in a controlled environment that has high relative humidity, use conductors that can discharge the material, ionise the atmosphere, or apply hydrophilic chemical substances. Chemical products that confer an anti-static effect on synthetic fibres form, on the fibre surface, a thin film whose electrical conductivity is higher than that of the fibre.
These substances are anionic, cationic, amphoteric, or even non ionogenic products. The conductivity of a synthetic fibre is thus increased when it is covered with a surface-active substance in which the hydrophobic groups are oriented towards the fibre and the hydrophilic groups are oriented away from it.
The presence of mobile electrical ions is, however, important.
Depending on the substantivity of the chemical products used, it is possible to choose between different application processes: immersion, exhaust or padding.
Anti-static finishing treatments are rarely applied through spraying. Chemical products that have the capacity to confer a permanent anti-static effect condense at high temperatures; they can even condense when stored at ambient temperature in hermetically sealed rooms or containers (as can epoxy resin-based products).
All the anti-static products available on the market can be applied by padding, while only a few can be applied using the exhaust process. The material is immersed in liquor containing the anti-static chemical product, squeezed (to 40-60% absorption) and finally dried in a stenter at 80-100°C.

If the stenter is equipped with additional chambers that can be used to carry out heat setting processes, then it is also possible to condense, at the same time, anti-static products able to confer permanent effects.

Mothproof finishing

In certain ambient (humidity and heat) conditions, cellulose can be permanently damaged. This damage can be due to depolymerisation of the cellulose or to the fact that certain microoganisms (mildews) feed off it. The situation is worsened, during long storage periods, by the presence of starch finishing agents.
This damage can be prevented by the use of antiseptics, bacteria controlling products containing quaternary ammonium salts, and phenol derivatives. Dyestuffs containing heavy metals can also act as antiseptics. Permanent modification of the fibre (cyanoethylation) is another possibility.

Antibacterial finishing

In principle, antibacterial treatments for fabrics work by limiting the growth of the microorganism population. This also leads to a reduction in the quantity of unwanted by-products. The active principles that limit the growth of the microorganism population are known as "antimicrobials". Here, a distinction can be drawn between those that have a bacteriostatic effect, i.e., that limit growth, and those that have a bactericidal (or lethal) effect.
The former have the following aims:

- to prevent the transmission and propagation of pathogenic microorganisms (hygiene sector);
- to reduce unpleasant odours due to bacterial degeneration (deodorisation);
- to prevent loss of an item's suitability for use (as a result of decomposition of fibres following attack by microorganisms).

There are various chemical and physical possibilities that can be considered in the production of antimicrobial fabrics. In practice, the antimicrobial effect is obtained through the application of specific chemical products during the finishing stage, or through the incorporation of these substances into chemical fibres during the spinning process.
These possibilities are:

- the addition of bactericidal substances to the spinning solution, prior to the extrusion stage – substances like Triclosan (2,4,4-hydrophenyl trichloro (II) ether), a member of the antiseptic and disinfectant family. Triclosan is a halogen-containing derivative
- of phenol, and is used in cosmetics and toothpastes. It has a wide range of action against gram-negative and gram-positive bacteria. This compound, thanks to the presence of the acaricide benzyl benzoate, also

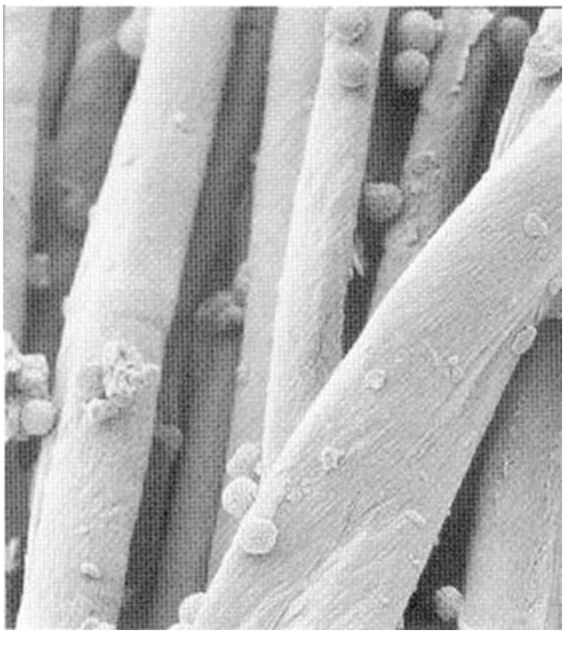


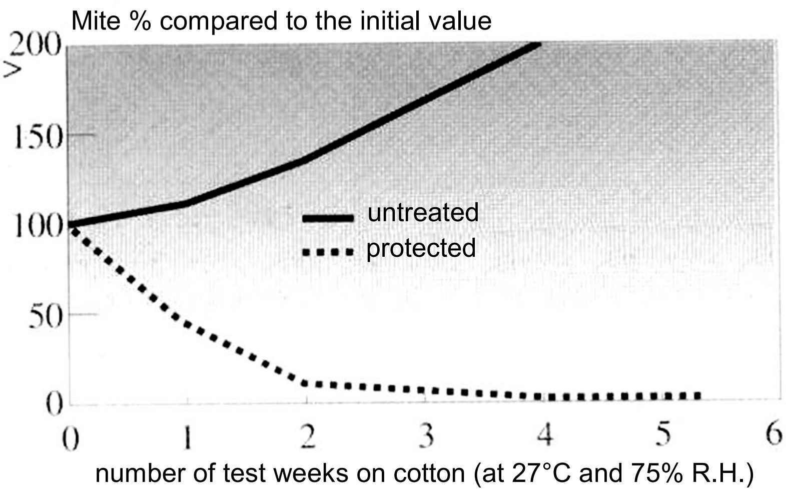
Fig 188 Allergen-containing mite excreta on fibres : they are initially covered by a mucous layer which later decomposes into tiny particles

offers protection against mites and is used in acaricide (spray or powder) formulas, as well as in a solution (25% concentration) for the treatment of scabies. This compound is non toxic. Benzyl benzoate is an acaricide that acts, chemically, directly on the mites.

- A different method for the production of antimicrobial and fungicidal fibres has been adopted by an English company. Its "Stayfresh" fibres exploit the properties of silver and silica, both of which, on coming into contact with water or humidity, arrest the growth of bacterial populations in carpets, fabrics, furniture, resses and bed linen, by cutting off a source of their nutrition. As well as having antimicrobial and fungicidal properties, these fibres are safe, non toxic and inorganic because they guarantee total mildew and fungus control, preventing the propagation of bacteria such as Escherichia coli and Staphylococcus aureus.
- Modification through grafting or other chemical reactions. It is in this sector, that the Institut Textile de France in Ecully has developed the so-called biotextiles. In these products, the chains of molecules containing antiseptic substances are grafted onto the base polymers of the raw fabric. The base polymers are activated by electronic rays and, in the course of the process, they are refracted in given positions, into which is inserted the first graft molecule. The chains of polymers, which grow laterally from the first molecule, confer on the fabric its bactericidal properties. In the event of direct contact, these fabrics act very rapidly against bacteria and their bactericidal property remains intact even after washing.
- Fibre blends.
    - Textile finishing treatments with specific active principles. Following heat treatment (drying, condensation), these substances, being incorporated into polymeric and resinogenic finishing products, become fixed to the structure of the textile.

Antibacterial finishing products

Man has adopted antimicrobial substances since ancient times, a fact that is demonstrated by their use in Egyptian mummies and in similar applications in other cultures.



In this regard, the protection and preservation of fabrics, too, have long fulfilled a role of the utmost importance. The need to protect and preserve is still fundamental in many textile applications today. “Antimicrobials” are protective agents that, being bacteriostatic, bactericidal, fungistatic and fungicidal, also offer special protection against the various forms of textile rotting. The main antimicrobials include phenolic active principles, quaternary ammonium salts, and organic-metallic (Hg) compounds. The chemical products listed in the table on page 156 can be used to obtain antimicrobial effects in fabric finishing and in the production of chemical fibres. A different method for the production of antimicrobial and fungicidal fibres has been adopted by an English company.

Its "Stayfresh" fibres exploit the properties of silver and silica (silicic acid), materials that react with water and humidity, cutting off a source of nutrition of the house mite and shrinking its population.

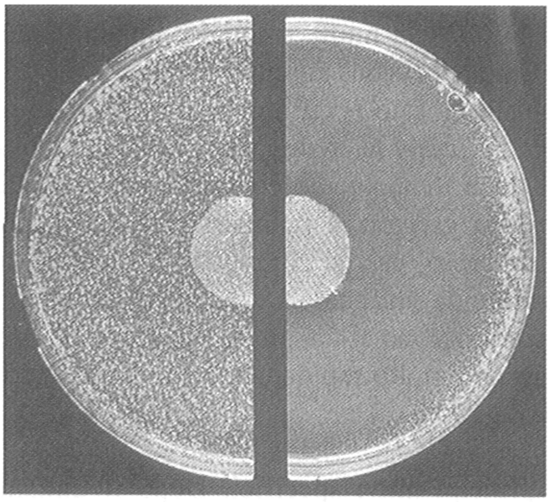


Fig. 189 Specific treatments create a zone in which bacteria cannot proliferate, as the test in the figure demonstrates

Antibacterials	Materials
Aniline	3,4,4-trichlorocarbaniline
Phenol	Biozole, thymol, sodium alkylenbisphenol salt
Guanidine	1,1-examethylene up to 5-(4-chlorophenyl) diguanide digluconate; diguanide polyexamethylene hydrochloride
Imidazole	2(4-thiasolil)benzimidazole, benzothiazole
Inorganic compounds	Silver zeolite; titanium oxide; silver silicate; silver sulphonate; ferrous phtalocyanate; copper sulphonate
Natural products	Glucosane; propolis; hinokichiole
Surfactants	cloruro di poliossilalchiltrialchilammonio - Organic silicone with tertiary ammonium salt; octa-decilidimethyl(3-trimethoxypropyl, ammonium chloride). Tertiary ammonium salt: didecilmethylammonium; exadecilperydium; cetyldimethylbenylammonium; polyoxylalkyltrialkylammonium

Plasma treatment

The plasma state is often described as the “fourth matter state”, as it shows a behaviour considerably different from gas and common fluids and is more reactive than these states.

It is composed, without any concentration limits, of an aggregate of electrically charged particles, electrons and neutral atoms, and stands at an energy level significantly higher than solid, liquid or gaseous phases.
The components of this physical state, which is on the whole neutral, are mainly ions, electrons, photons, neutral atoms and molecules in ground or excited state. Thanks to the presence of electrically charged particles, plasma is sensitive to the action of external electric and magnetic fields.

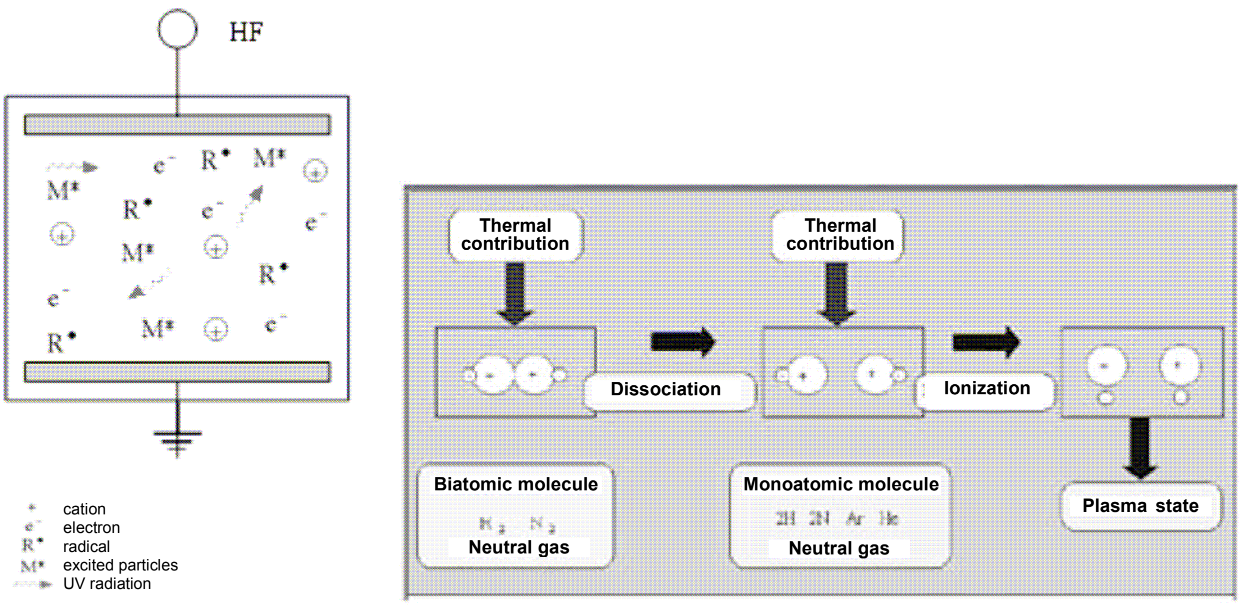


Fig. 190 Plasma formation cycle

When in energically excited state, atoms are reactive species which can originate a wide range of interactions with the surfaces and produce certain plasma processes.

- **grafting:** with this treatment, particular chemical groups formed during plasma phase are inserted on the surface of the material to be treated. Depending on the kind of gas used, it is possible to clip on the substrate oxidrilic, aminic and carbossilic groups. The effects of grafting cannot be noticed over 100 Å from the surface, therefore the structural properties of the material remain unchanged. Tis process can be used to improve the adhesion and wettability of the polymers and permits for instance to transform a water-repellent surface into a hydrophilic surface. On the contrary same treatment using fluorine-based gas can be used to lend to the textile material pronounced characteristics of water- and oil-repellency.

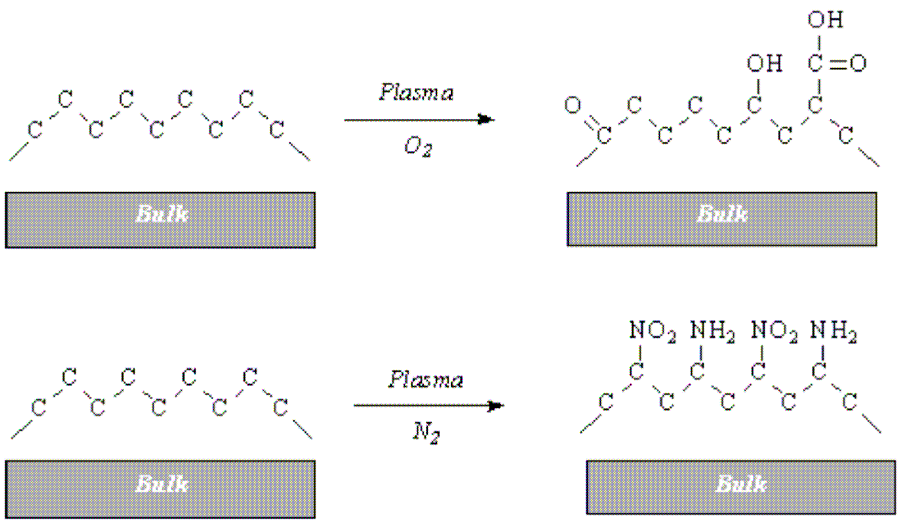


Fig. 191 Scheme of grafting process through plasma

- **etching:** this treatment, which is also named plasma cleaning, is used for the superficial ablation of the organic surface contaminants, mostly composed of oil or fats to improve the performances of subsequent processes (dyeing, finishing). The exposure to plasma can be used in this case to sterilize surfaces against microorganisms (spores, fungus, bacteria and virus), with the possibility to operate at room temperature with reduced treatment times and without the support of chemicals.

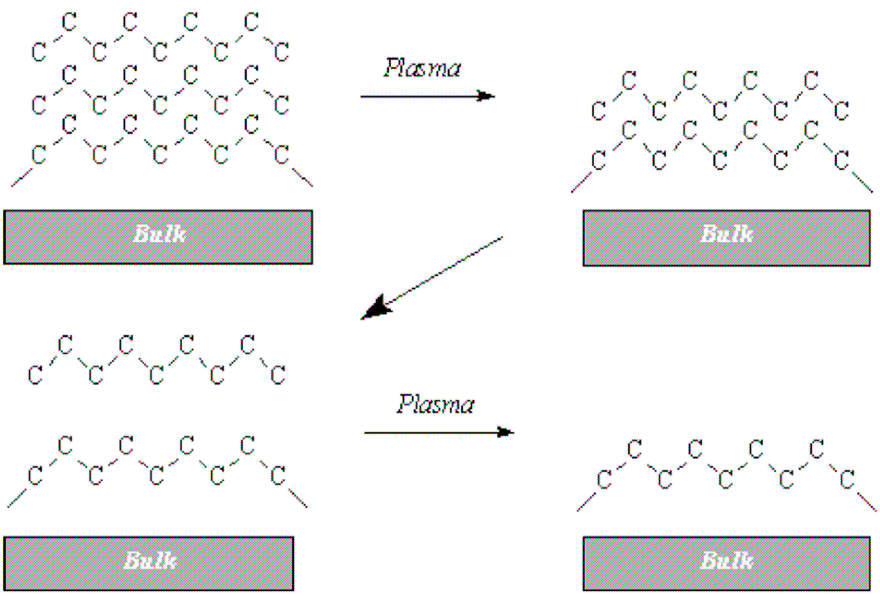


Fig. 192 Scheme of superficial ablation process through plasma etching

The **PECVD** process (Plasma Enhanced Chemical Vapour Deposition) permits the deposition of thin films through the use of an organic gas or of a gas containing atoms capable of forming polymers. As to its application in the textile sector, this process permits to deposit polymeric films with properties depending on the reaction conditions, with a thickness varying from 100 to 10000 Å and with a chemical composition such as to provide the treated surfaces with different properties and functions. The deposition of the thin films develops along three reaction mechanisms:

Radicalic reaction : R• + S• → RS

Ionic reaction : R+ + S- → RS

Atomic reaction : A + B + A → ABA

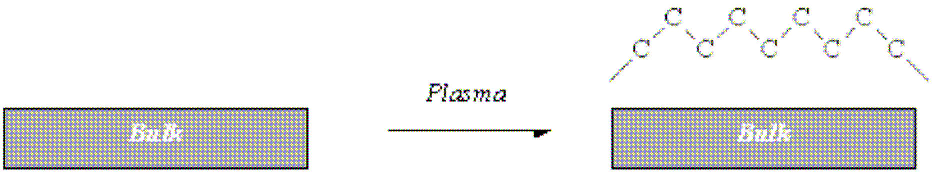


Fig. 193 Scheme of thin film deposition through PECVD plasma

The surfaces of the fabric exposed to the action of the plasma are modified, both physically (roughness), as well as chemically, to remove organic particles still present and to prepare for the successive introduction of free radicals and new chemical groups inside the molecular chain on the surface of the material. The mechanical properties remain, on the other hand, unaltered, as the treatment is limited to the first molecular layers. The working process is dry, environmentally friendly and inexpensive; a fabric is normally treated at a speed of 13-20 m/min, with a consequential time of exposure to the plasma of around 30-40 seconds, using as mentioned above a gas (in the majority of cases it is air) and electrical current. The tension during the winding of the web is controlled by a load cell capable of maintaining the tension previously established, even though this is very low; it follows that also with "melt-blown" type fabrics which generally have the lowest tensile strength can be successfully adapted. The fabrics treated with plasma present a high superficial energy, assuming however high hydrophilic properties, though they are originally water repellent. This permits on the one hand the elimination or the limitation of solvents in the successive processing steps, on the other it makes the chemical products used for finishing more efficient for the best and most uniform deposit of the product itself and for the adhesion of a chemical type between the active group present on the surface of the fabric treated and the coating product.

It is possible therefore to obtain anti-static, antimicrobial, stainproof or flame retardant fabrics, with clearly higher performance, with better resistance to washing and wear and tear, and with finishing that is at times more simple and less expensive.

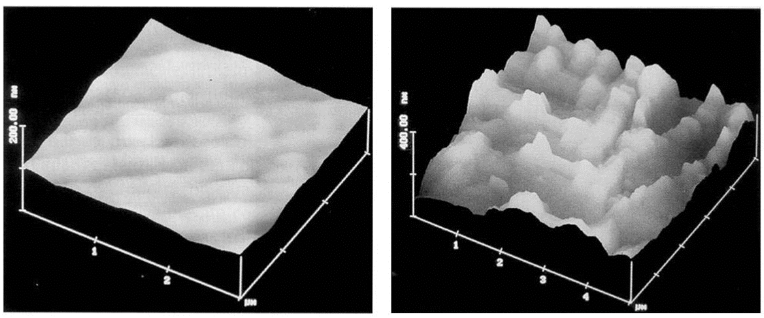


Fig. 194 a) Nonwoven substrate before plasma treatment
b)Nonwoven substrate after plasma treatment

The resistance to peeling and fibre-matrix interface resistance, which are the fundamental characteristics typical of multilayer products such as:

- composites (e.g. Kevlar, glass, carbon/epoxy resin or polyester),
- laminated textiles (e.g. fabric/nonwovens, fabric/film),
- coated textiles (e.g. fabric/resin or polyurethane foam)
-

is much higher than the values of the same products obtained without plasma treatment. In fact, for fabrics made from natural and man-made fibre, the plasma treatment also improves dyeability characteristics, such as intensity (approx. 30%) and solidity (I point), and in particular, for animal fibres, it confers strong anti-felting characteristics. This means that the chlorine process can be avoided and therefore so too are the damaging physical properties this creates for the fabrics themselves, but also for people and the environment, as chlorine is a pollutant.

The effects of this plasma treatment on surfaces are significant and uniform along the length and width, and they last a long time. The increase in surface energy of the fabrics means that chemical products containing solvents can be entirely eliminated from the conventional process necessary to uniformly wet the fabric surface. Furthermore, as the plasma treatment is efficient only on a level of the first surface layer, no damage to the physical properties intrinsic to the textile are noticed.

It follows from the very interesting applications of the plasma treatment that also applications of nonwovens have become apparent, having a destination of use among other things in air and liquid filtering, synthetic leather, cloths, artificial limbs, biomedical and protective wear, footwear and sportswear.

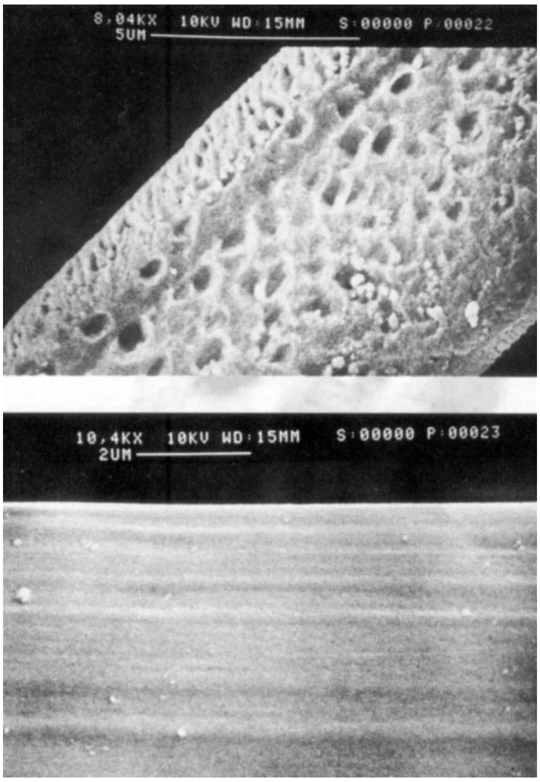


Fig.195 Natron plasma-treated (top) and untreated (bottom) silk fibre

Laser treatments

The term “laser” is the acronym for “Light Amplification by Stimulated Emission of Radiation” and describes an electromagnetic radiation which has an emission presenting particular characteristics:
Unidirectionality: laser beams propagate in a clearly defined direction, unlike the light of a common incandescent lamp which radiates light in all directions. A beam of argon laser with initial section of one centimeter diameter widens up until attaining a diameter of three centimeters after covering a distance of 500 meters.
Monochromaticity: laser beams show always a constant frequency owing to the stimulation mechanism of the radiation emission by the active material, which can be solid (ruby, Nd-YAG, etc.), ,gaseous (CO_2, argon) or liquid (dyestuff laser)
Coherence: the unidirectionality of the laser beams is bound to spatial coherence and is a consequence of the structure of the resonant cavity formed by two parallel mirrors producing at their exit a photon beam directed exactly perpendicularly to their surface.

The mechanism responsible of the laser beams emission is radiation-stimulated emission. When an atom receives an energy contribution such that one of its electrons has an energy level higher than its basic state, it shows the tendency, while restoring the initial conditions, to emit a photon, namely an electromagnetic radiation of ΔE energy level corresponding to the energy differential between the excited and the basic state. Around 1920, Einstein discovered that by irradiating the excited atoms with energy photons ΔE, the laser emission is stimulated. The emitted photons have same characteristics in terms of direction and frequency as the incident photons and move in phase with the stimulating photons. This phenomenon is named emission through stimulation. The table hereunder lists some of the most common laser types with the relevant wavelength of the main emission. The unceasing search in the textile sector for innovative, cost-effective and ecological treatment methods led to the experimentation of laser treatments on fibres and fabrics. As a matter of fact it is possible to use this tecnology with practically no environmental impact in the pre-dying processes (scouring and bleaching) and in the finishing treatments.

Laser types	Active mean	Main Å (µm)
Laser in solid state	Ruby	0,6943
	Nd^3+: YAG	1,064
	Er^{3+}: silicon fibres	1,55
Junction laser	AlGaAs/GgaAs	0,63 – 0,9
	InGasAsP/InP	= 1 – 1,7
	CO_2	10,6
Gas laser	He - Ne	0,6328
	Ar^+	0,515
Excimer laser	KrF excimers	0,248
	ArF excimers	0,193
Dyestuff laser	Rhodamine - 6G dye (organic molecules)	tunable 0,56 - 0.64

Fig. 196 Detail of laser marking

Laser sources are available in a range of various power factors: 30, 60, 100, 240, 300 and 400 Watt. The source height in respect to substrate level varies from 150 to 1200 mm. The beam is conveyed through a series of flat mirrors inside tubes running along the entire route. Flat mirrors characterized in particular by a high superficial quality are used. The requested planarity level is in fact much higher than the typical mechanicaltreatments and depends on the wavelength of the used source. In order not to introduce significant deformations of the laser beam, its precision (deviation from the ideal profile) must be $<\lambda/10$. In case of special applications, this value can reach also $\lambda/40$. This means, that in case of a CO_2 laser (λ=10,6) a good mirror should ensure an accuracy of about 1 μm in the conveyance of the beam bundle. Much more complex is the manufacturing of optics for UV rays (for instance for λ=0,193 μm); a good quality mirror operating in this range should in fact show an accuracy of 0,01 μm.
The mirrors can be classified in two categories: metallic mirrors and mirrors in vitreous substrate. Metallic mirrors are used in combination with sources of high power (typically CO_2). They have in fact the big advantage of direct cooling by means of a circuit of water circulating in their interior. They are however used only for laser with high wavelengths, owing to manufacturing difficulties and are therefore not suitable for sources with visible wavelengths. The typical materials are copper and molybdenum. The other typology includes mirrors, which combine a substrate (typically amorphous quartz) with a suitable plating or dielectric lining. In this way the very high characteristics of the substrates are coupled with the reflectivity of the linings (which too are quite high), and it becomes possible to design mirrors suited for all kinds of laser. The only limit is given by the power these mirrors are able to stand, as it is not possible to cool them.
As soon as the laser beam reaches the processing zone, it has to be adapted to the various requirements. In general it is focused on a small spot by means of proper optics. There are two solutions for beam focusing:
The first solution, used only in the systems provided with CO_2 laser, requires the use of metallic (copper) parabolic mirrors. With this kind of mirrors, advantage is taken of the geometric property of the paraboloid to concentrate a bundle of tallied beams on its own focus.
The second solution requires the use of one or more lenses which focus the bundle of beams on a spot, the dimensions of which depend on the diffraction as well as on the aberrations.
The whole system is managed through a software which controls the laser source, the mirrors and the sliding speed of the fabric in the cabinet, thus enabling the development of numberless patterns.

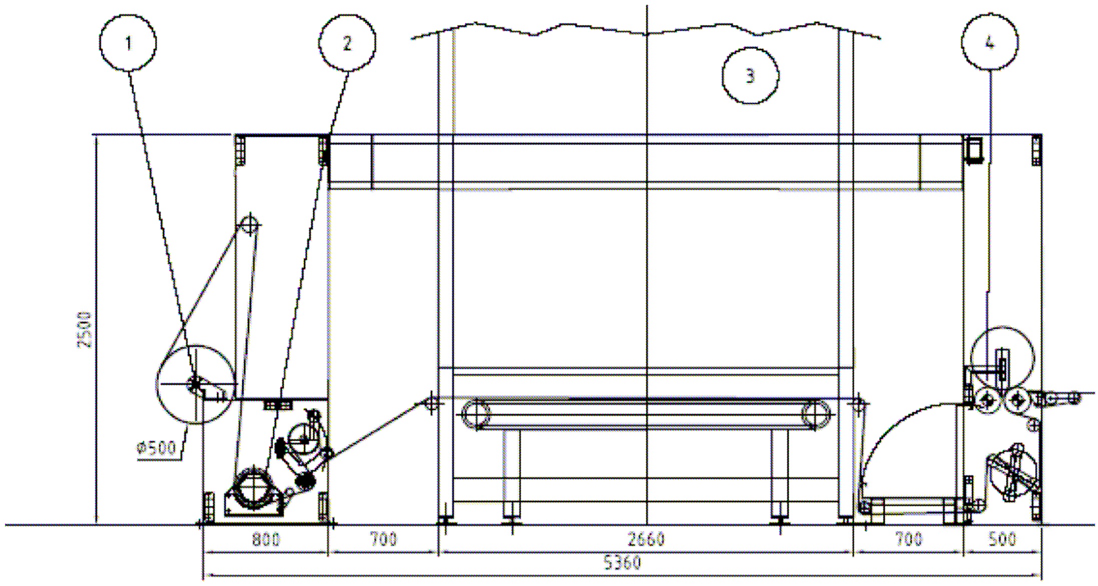


Fig. 197 Scheme of a machine for fabric laser treatment

1. *support for small roll*
2. *center square with movable staves*
3. *cabin for fabric treatment*
4. *winder for small rolls*

Fig. 198 Laser treatment machine

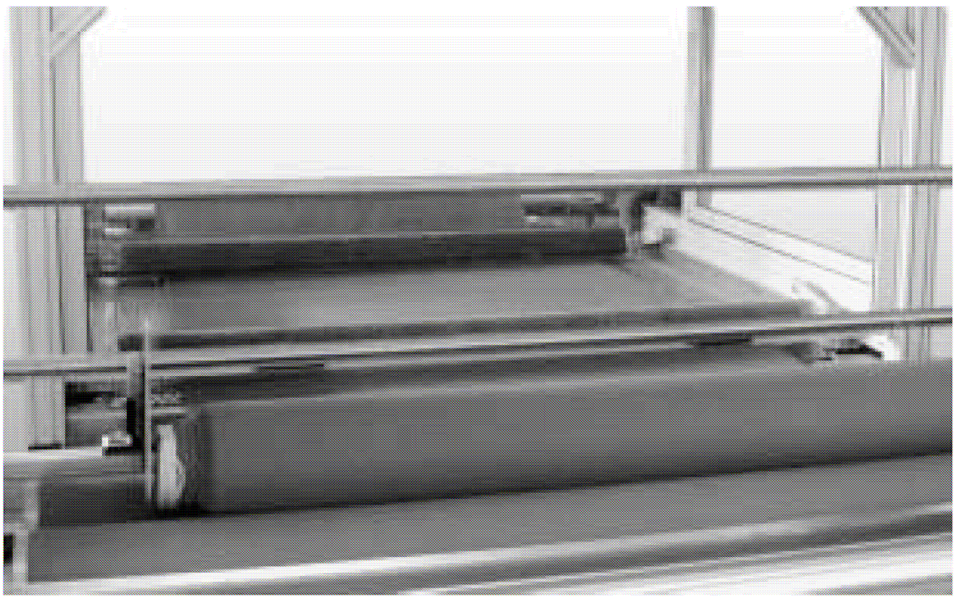


Fig. 199 Detail of laser treatment machine

The above machine operates with a 400 Watt CO_2 laser and is equipped with an aluminium suction work-top (800 x 800 mm). The minimal engraving diameter is 0,25 mm.
Laser treatment is widely used to create particular pattern effects on fabrics or directly on finished garments. It permits to engrave patterns (by modifying fabric surface or eliminating parts of the fabric), to modify colours acording to pattern, to produce artificial ageing of fabric surfaces or of coated fabrics, as well as to modify the structure of the textile product (provided it is made of man-made fibres) through partial melting.

Enzyme treatments

This chapter aims to propose and develop, though in a summary form, the enormous possibilities and advantages, of an environmental and ecological nature, deriving from the use of enzymes in various textile finishing operations as an alternative to traditional processes and chemical products.
Enzymes are proteins formed by long linear chains of amino acids linked by peptidic bonds. They are present in all living cells which carry out vital functions in the metabolic process, of growth and cellular reproduction, transforming and conserving energy. They are biological catalysts capable of notably accelerating the chemical reactions which occur in living organisms.
They are produced by cells, but they are not viruses or bacteria and they cannot reproduce autonomously; they are therefore "alive" even though not biologically active, in determined conditions of pH, temperature, liquor composition and so on.
In the past, enzymes used industrially were obtained by:

- extraction and purification of animal organs or tissues (pancreatic trypsin) or from vegetal sources (papaine);
- techniques of fermentation of selected microorganisms (bacterial amylase).

The latest developments in genetic engineering and bioengineering have totally revolutionised the technological scene widening the outlook for the types of applications and expanding the enzyme market. In particular, protein bioengineering has permitted:

- the adaptation of biochemical characteristics of an enzyme under conditions of the industrial process;
- the creation of new enzymes with catalysis techniques which do not exist in nature;
- the alteration of the properties of enzymes such as stability, activity, composition and so on.

Old and new enzymes used in textiles
- **Amylase**: desizing.
- **Cellulase**: biopolishing of fabrics and cellulose garments, stone wash of denim garments.
- **Protease**: treatment of protein fibres (silk and wool).
- **Catalase**: elimination of hydrogen peroxide after bleaching.
- **Laccase and peroxides**: oxidation of dyes.
- **Lipase**: elimination of natural triglycerides (in scouring) or present in desizing (tallow compounds).
- **Pectinase**: bioscouring of raw cotton.

From the end of the eighties till today, the biggest development of modern enzymology was made in the textile segment with the introduction of new cellulase for finishing cellulosic fabrics and garments, of protease for the treatment of wool and silk, of catalase for the elimination of hydrogen peroxide after bleaching, of new amylase types for desizing processes, and of laccase for oxidation of dyes such as indigo.
A new and very interesting application currently being developed is bioscouring raw cotton using alkaline pectinase, as an alternative to traditional treatments involving caustic soda and high temperatures.
As a large part of fibres processed in the textile industry are of a cellulosic nature (cotton, linen, viscose, Lyocell from wood pulp etc), this segment represents a great opportunity for enzyme treatments. In particular, the uses of cellulose in the textile industry are very varied and in continuous evolution thanks also to the studies carried out in recent years in Italy by Mr Galante and Mr Monteverdi from the Lamberti research centre.
Of the most important results from current research, the following is worthy of mention:

- enzymatic stone wash of denim garments
- biopolishing, meaning superficial defibrillation of fabrics or garments, before or after dyeing;
- removal of the imperfections of immature or "dead" fibre and cotton;
- the modification of hand characteristics and the permanent softening of fabrics;
- improvement of the quality of printing;
- a possible increase in affinity for dyes.

The uses of cellulase in textiles permits the development of a new range of finishing and "fashion effect" industrial processes for fabrics and garments, with an absolutely environment-friendly approach, as it is entirely based on completely biodegradable biological agents, with the following advantages offered by the enzymatic stone wash with cellulase compared to the sole use of pumice stone:

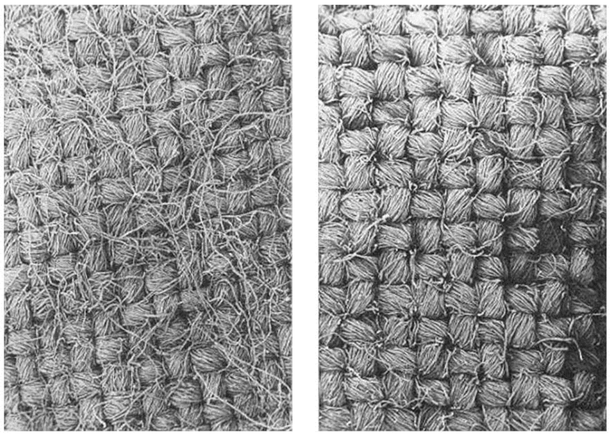


Fig. 200 Effect of biopolishing: before (left) and after (right) enzyme treatment

- shorter treatment times;
- minimal damage to machinery;
- increased machine load for every work cycle, with higher productivity in laundering;
- reduction of tearing caused by pumice stones;
- substantial reduction or even elimination of the production of pumice dust, to be disposed of as solid refuse or waste;
- better consistency and reproducibility of stone wash treatment, with also better flexibility of treatments and better final looks obtained;
- less intense manual work in laundering;
- better versatility in using the machine;
- in the case of cellulase liquid formulae, the possibility of using the automatic and computerised dosage systems;
- improved environmental and laundry work conditions.

Biopolishing or biofinishing with cellulase is carried out both on pieces as well as made up garments and it can be compared to an enzymatic “singeing process”, carried out before dyeing or after dyeing also to give a sort of stone wash effect. It is widely used on made up garments, without technological alternative, while on a piece traditional singeing can be used. Nevertheless, in this latter case, that particular soft hand effect typical of cellulase cannot be obtained. Biopolishing treatments permit:

- Elimination of dead or immature cotton, of neps and surface hairiness.
- "Natural" softening with an improvement of hand and drapability.
- Permanent prevention of reiterated fibrillation and pilling.
- Increase in hydrophilic properties, particularly in the case of terry fabrics.
- Better cleanliness and brightness, as well as uniformity of dye.
- Better overall quality of the material.
- The possibility of creating finishings to suit new and original fashion effects.
- Use of an entirely environmentally friendly process.

Enzymatic finishing or surface biopolishing is the result of a combination of enzymatic hydrolysis and mechanical action, whose main factors to consider are:

Mechanical action

- Type, design and management of machinery.
- Process time
- Material load and liquor ratio

Enzymatic action

- Type and quantity of enzyme
- Time, temperature and pH of the process
- Nature and concentration of the chemical auxiliaries present
- Thermal and/or alkaline inactivation of the enzyme at end treatment.

Recent formulae of cellulase and amylase are available, to degrade amide and derivatives of cellulose (such as CMC), and more recently a combination of amylase plus lipase has also been proposed.
There are various scientific developments under way on amylase which could lead to results of a certain interest also for the textile industry, for example:

- Amylase with acid pH, of possible use for desizing in combination with acid extract scouring.
- Amylase with alkaline pH (around 8-9) for desizing in combination with bioscouring with pectinase or however with pH closer to that of bleach.
- Amylase resistant to oxydising condition, capable of being used at the same time as a delicate bleaching process.
- Amylase with activity and stability independent to the presence of calcium ions, which would avoid the addition of calcium chloride in the liquor and would permit the use of stronger chelants or sequestering agents, without risking inactivating the desizing enzymes.

In treating natural fibres composed of proteins, like silk and wool, protease can be used. The latter is composed of a large family of enzymes specific for hydrolysis of proteins, being able to hydrolyse the peptidic link between adjacent amino acids.
A very vast range of protease exists in nature, from every possible source of life (microorganisms, plants, animals) with very diverse properties, different optimal pH levels and temperature, and other biochemical characteristics.
Nevertheless, the sources of industrial protease are by now almost solely microbes obtained by fermentation techniques. Vegetal protease, like papaine and bromelaine, or animal protease like trypsin, chemostrypsin and pepsin, have almost been entirely abandoned for industrial type processes.
Enzymatic degumming of silk using protease permits the sericin to become hydrolysed and at the same time other protein residues deposited by the silkworm.
Compared to traditional degumming of silk using soap in alkaline conditions, enzymatic degumming, if carried out correctly, prevents damage or weakening of the fibre from occurring, obtaining a more uniform coloration, with a less harsh environmental impact compared to surfactants.
Currently, particular protease is used also in the preparation and finishing of silk pieces or articles.
Through this enzymatic treatment, special effects are sought for softening and for the hand (e.g. peach-skin, draping, suede-like effects etc) demanded by fashion or the market.
It should, however, be underlined that, while protease on silk can certainly give interesting and commercially valid results, they are still difficult treatments to carry out correctly in order to avoid irreversible damage.

Possible uses of enzymes:

1) *Limit the typical tendency of wool to "shrink and felt"*
2) *Solve dimensional stability problems*
3) *Provide "machine wash" characteristics for the fabric*
4) *Eliminate the negative properties emerging in fabric care processes (e.g. hygroscopic expansion)*
5) *Enhance the fabric colouring*
6) *Prevent the pilling effect after some finishing processes*
7) *Eliminate motes (in alternative to the conventional carbonising methods)*
8) *Bleaching of wool*
9) *Wool fabric bioscouring*
10) *Possibility of enhancing the original fineness and softness characteristics of wool*
11) *Enhance the evenness of wool fabric fibres subjected to pre-dyeing treatments*
12) *Obtain stone-wash effects on yarn dyed fabrics, but above all on piece-dyed wool fabrics*
13) *Improve the imbibition properties of wool fabrics*
14) *Possibility of obtaining combined "effects" to ensure flame-retardant, water-repellent properties, etc.*

One of the intrinsic properties of wool is its tendency to felt and shrink when wet under conditions of mechanical agitation.
In relation to the various theories proposed to explain this property it is generally accepted that the "differential frictional effect" (DFE) plays a fundamental role in the process. The DFE is correlated to the morphological scale-like structure of the fibres, because of which they can move only in a unidirectional manner towards their roots, but not in an opposite direction, "blocking each other" therefore if subjected to mechanical stress when wet. In practical uses it is extremely convenient to use shrink proof wool, partly due to limitations imposed by dry cleaning and market demand for risk-free home washing of woollen garments.
The techniques used to produce shrink proof wool modify the fibre with rather drastic oxidative treatments, at times followed by applications with cationic resins to preserve the dimensional stability of the wool.
The majority of these processes use chlorine gas, or chlorine or hypochlorite salt. Nevertheless, due to the growing limitations of use of chlorine as an oxidant, there is a growing interest in using more ecological and safer alternatives to produce shrink proof wool.
Wool can be considered an almost ideal substrate for many enzymes, like heterase, protease, lipase and other enzymes which break the disulphide bonds of cystins in keratins. The fibres of wool are, in fact, essentially composed of protein and lipids, and are formed by two main morphological structures: the cuticle and the cortex.

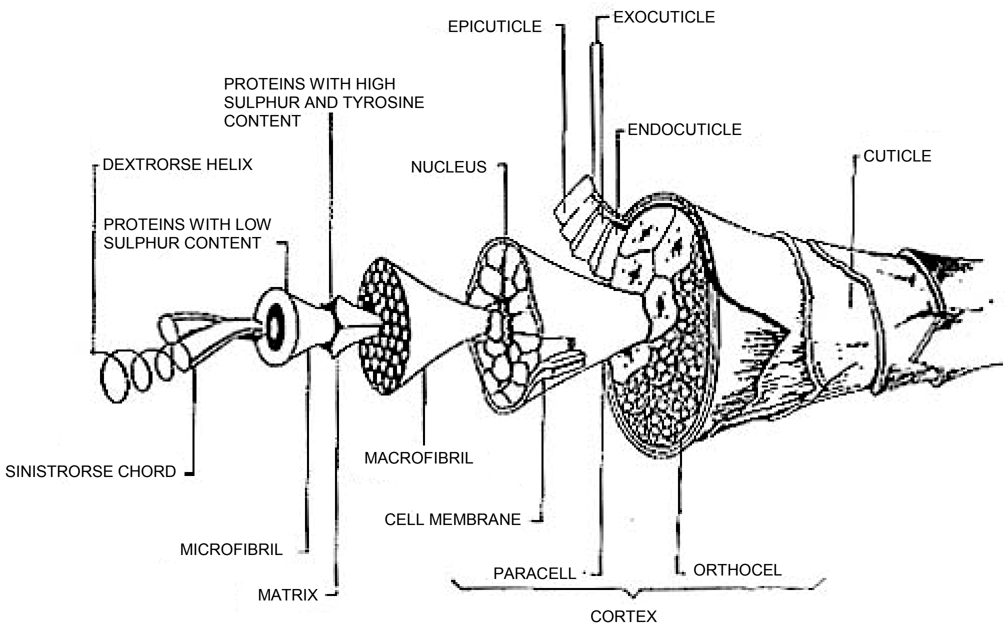


Fig. 201 Morphological structure of a wool fibre

The cuticle confers to the fibre the scale-like outer look and it is in turn composed of 75% protein and 25% lipids.
The common anti-felting treatments with chlorine cause to a varying extent a functional modification (resistance to felting) associated with a morphological modification (a marked filing down of the scales of the epicuticle easily seen with a SEM).

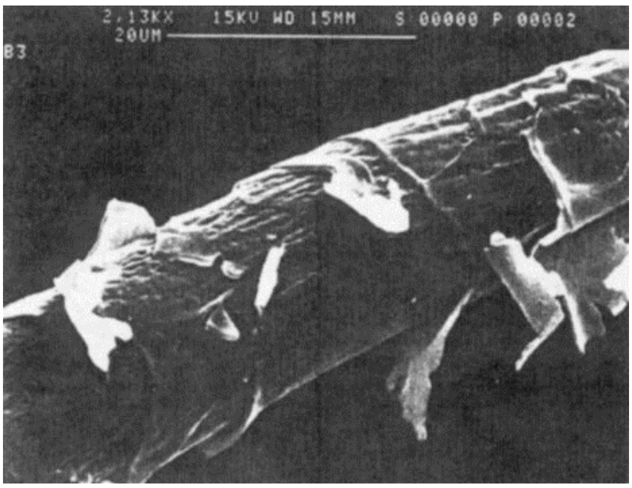


Fig. 202- SEM Photograph showing the damaged wool

On wool, with some protease base enzymatic preparations, interesting effects can be achieved which have some commercial importance, such as:

- Softening and modification of hand characteristics
- Anti-pilling and surface cleaning
- Better drape
- "Aged" look on garments
- Improved comfort.

In the case of anti-pilling treatment for wool woven and knitted fabrics, a protease has been launched on the market which can be used solely on pre-chlorinated wool. Unfortunately, treatments using only protease do not confer anti-felting properties on wool.
In the textile industry, particularly in dyeing, catalysis represents a safe and ecological innovative application for eliminating hydrogen peroxide after the bleaching process and before dyeing. The use of this enzyme instead of more traditional chemical reactants (e.g. reducing alkaline detergents such as hydrosulphite or thiosulphate, magnesium salts etc) permit:

- to avoid repeated rinsing cycles, leading to considerable savings in water.
- to carry out dyeing in the second liquor rinse or even in the first, following corrections of temperature and pH.
- to reduce processing times.
- to lower energy requirement.
- to avoid polluting chemical effluents.

Recently a new redox enzyme (laccase) was also proposed for the irreversible oxidative breaking of indigo, to give denim garments a "clean" backstaining (using low enzyme quantities) or bleaching effect (using higher quantities).
Finally, a new process for the enzymatic scouring or bioscouring of raw cotton was presented for the first time .
The bioscouring of raw cotton as an alternative to alkaline scouring has been studied in depth over recent years. The basic idea is simply that of hydrolysing using enzymes those non-cellulosic components responsible for water repellency of cotton, using a specific degradation process in delicate pH and temperature conditions, then removing them with a successive hot rinse.
The enzymatic process are very specific and can therefore be direct only towards components which need to be removed, maintaining the cellulose intact, with therefore a lesser loss of weight and resistance to fibre, a lower COD and BOD in plant waste water.
Considering the composition of the entire cellulose fibre, pectin, protein, wax and hemicellulose, various families of hydrolytic enzymes have been evaluated in bioscouring, used individually or in combination, such as: cellulase, pectinase, protease, hemicellulase, and lipase.
From many studies published or presented at scientific symposiums it has emerged that a treatment with pectinase followed by a hot rinse is able to confer hydrophilic properties on cotton and make cotton absorbent as well as being a chemical scouring process.

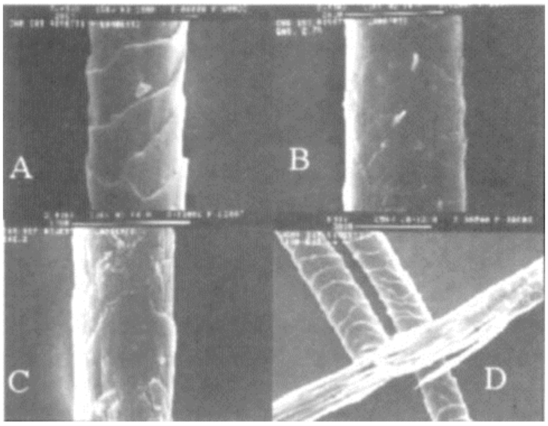


Fig. 203 Treatment of wool with protease A: untreated wool; B: wool treated with specific products; C: wool treated with protease; D: wool damaged by protease

On the contrary, protease, hemicellulase and lipase do not seem to offer positive effects, while cellulase can weaken the fibre. This result is explained by the facts that:

- Waxy material, pectic substances and proteins from the cuticle and primary wall are associated and present in an amorphous state.
- The primary wall has higher amorphous properties than the secondary one.
- The external surface of the fibre can therefore be hydrolysed more easily than its core.

The pectinase destroys the structure of the cuticle, hydrolysing the pectins and removing the links with wax and protein, as well as between these and the remaining fibre structure. The pectin links the wax to the cellulose of the primary wall, but it is not necessary to eliminate all the pectin for providing hydrophilic properties. Even when 30% of the residual pectin remains on the fabric, a wash at 80-90°C after a dwelling stage eliminates the solubilised waxes.
This pectinase is to be more exact, a lyase pectin, it acts therefore on the pectin independently to its degree of methoxidation. Bioscouring is applied on woven fabrics in continuous processes and on knitted fabrics in batch processes. It can be applied with an exhaust process or by impregnation (pad batch) in a special buffer at pH 8-9 containing an imbibition agent, at a temperature of between 50 and 60 °C or lower and for variable times from some tens of minutes to some hours, depending on the fabric, the quantity and the dwelling temperature. In these conditions, it is also possible to combine the two treatments of scouring and desizing into just one operation, the conditions of use of pectinase and amylase being compatible. A hot rinse follows to eliminate the hydrolysed components and freed waxes. The efficiency of the bioscouring is measured mainly by the hydrophilic properties of the fabric treated. The same degree of hydrophilic properties are obtained with the drop test, comparable to chemical and enzymatic scouring.
The residual content of pectin is comparable in the two approaches, but it is not influential on the hydrophilic property, this being determined mainly by waxy components on the cuticle. On the other hand, with bioscouring alone, the motes are not eliminated (in fact it is a wooden material) and it does not increase the degree of white.
Both these aspects are however resolved in the successive bleaching.
Of the potential application and commercial advantages of the bioscouring, the following are worthy of note:

- Saving of water and energy.
- Lower environmental impact and easier to treat waste water.
- Better compatibility with other processes, machinery and materials.

- Lesser attacks on the fibre structure, loss of weight and resistance, with improved quality of the article.
- Improved hand characteristics.
- Possibility (still to be proven) of a higher degree of polymerisation of the cellulose and a lesser tendency of the fabric or fibrillation later pilling phenomena.
- Better and more uniform affinity for dyes.
- In the case of woven fabrics, the possibility to combine the two desizing and bioscouring steps in just one; in the case of knitted fabrics, combining bioscouring with biopolishing using cellulase, with a jet or overflow machine.
- Possibility of scouring cotton even when blended with more delicate fibres.

Bioscouring is therefore only in its infant stage as a proposal for large scale industrial application on woven and knitted fabrics as well as on yarns.
Laboratory figures and pilot tests are without a doubt encouraging, but it remains to be tested in an installation to say how valid and competitive this new textile enzymology process can be.
Until ten years ago, the use of normal amylase for desizing was more or less the only noted application and it would have been difficult to imagine such a boom in the development of new enzymes and their relative applications in the textile field.
There is still a lot of progress to be made, such as:

- costs must become more competitive;
- the ease of use and parameter control must be improved;
- the question of inserting enzymatic treatments stages in continuous processes;
- new enzymes must be developed, above all active in a wider range of pH environments and temperatures;
- rapid, simple and economic methods of enzymatic activity must be developed to offer the operator better control over the process.

Enzymology is however finding increasingly large space in the practice of preparing and finishing textiles. It is not a technology which eliminates either chemicals or textile machines, but it integrates well with these.
For a textile industry like the one in Italy, dependent for its commercial success above all on an excellent capacity and sensitivity to finishing textile goods, as recognised throughout the world, a good ability in enzymology becomes therefore an excellent factor linked to competitive advantage.

Finishing treatments of ready-made denim garments

The name "denim" indicates a particular kind of cotton fabric, woven with indigo dyed yarns in warp and raw-white yarns in weft. It is produced in different versions with various weights and different weaves (for instance four leaf twill, three leaf twill, broken twill, plain weave, etc.).
Two dyeing methods are available:
- rope dyeing
- open width ("shift") dyeing

Indigo dyeing of ready-to-wear garments offers several advantages over garments produced with yarn dyed fabrics or with piece dyed fabrics, even if dyed with the same dyestuff class, as:
- it ensures quick answer to market demands thanks to high production speed and to effective stock management;
- it ensures easy processing, as the phases of yarn package creeling and of warp beam production (which are very labour intensive) are no more necessary
- it permits to obtain a pleasant coordinate colour effect in garments or garment sets showing knitted or woven designs or also jacquard patterns applied with different types of yarns (fancy items).

The latest indigo garment dyeing process on the market outweighs the disadvantages of the existing processes, as it eliminates in a uniform way the superficial dyestuff in excess and oxidizes evenly the remaining material. This enables to obtain a better colour evenness and interesting levels of colour fastness and shade depth.

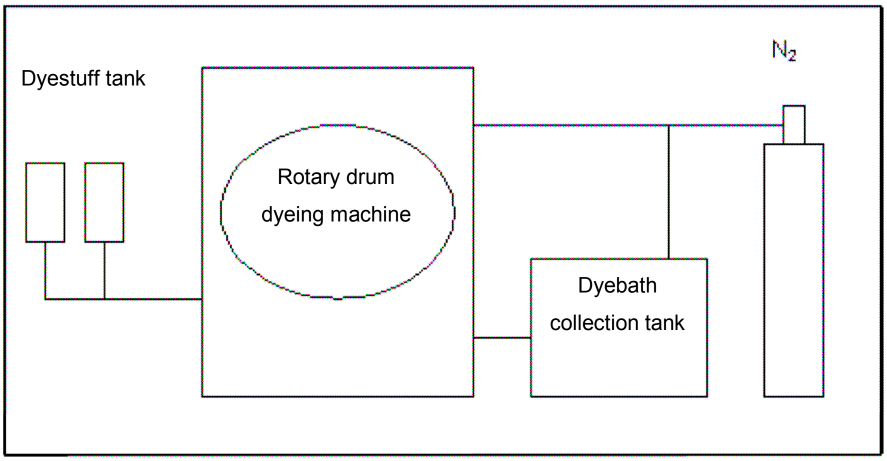


Fig. 203 Scheme of indigo garment dyeing process

In order to ensure good performances with this process, it is necessary to use closed systems to permit blowing in an inert gas (N_2, Ar), in order to prevent the oxidation of the indigo dye existing in leuco form in the treatments vats. After dyeing is completed, the exhausted or removed bath is collected and stored in a tank under similar not oxidizing conditions to be subsequently reclaimed. The dyestuff absorbed by the substrate is on the contrary oxidized by atmospheric oxygen. The dyed garment can be submitted to a wide range of finishing treatments; the most frequently used treatment, commonly named stone-wash process, exerts a combined physical and chemical action due on the one hand to the use of pumice stone and on the other to the use of reducing substances and enzymes.

Denim garments have been recently the object of new finishing technologies coping with fashion demand: strass application, pins, stitch-works, every kind of dyeing, bleached, re-dyed, pre-washed effects, various kinds of alterations (from superficial scrapings to localized tears or holes). In concomitance with this market evolution, technologies aimed at the attainment of increasingly innovative and original effects have proliferated: laser and spray decoration, sandblast, brushing and crushing effects, as well as coatings targeted at offering a sophisticated "extra-finished" denim and the utmost product personalization.

The first realizations were artisanal treatments on the fabrics before making-up, which had the objective of destroying the colour partly or completely. The effective industrial development of garment treatments took place with the introduction into the market of robotized systems which created endless possibilities to modify garment look and permitted above all repeatable results, creating plenty of patterns and variations simply by modifying the used software. The treatments to be carried out are of three kinds:

- localized wear of fabric surface by means of brushes with different form and bristle hardness;
- localized spraying on the fabric of colouring liquids or of colour corroding products;
- localized colour removal with laser beams, applied on the fabric so as to create pre-established patterns.

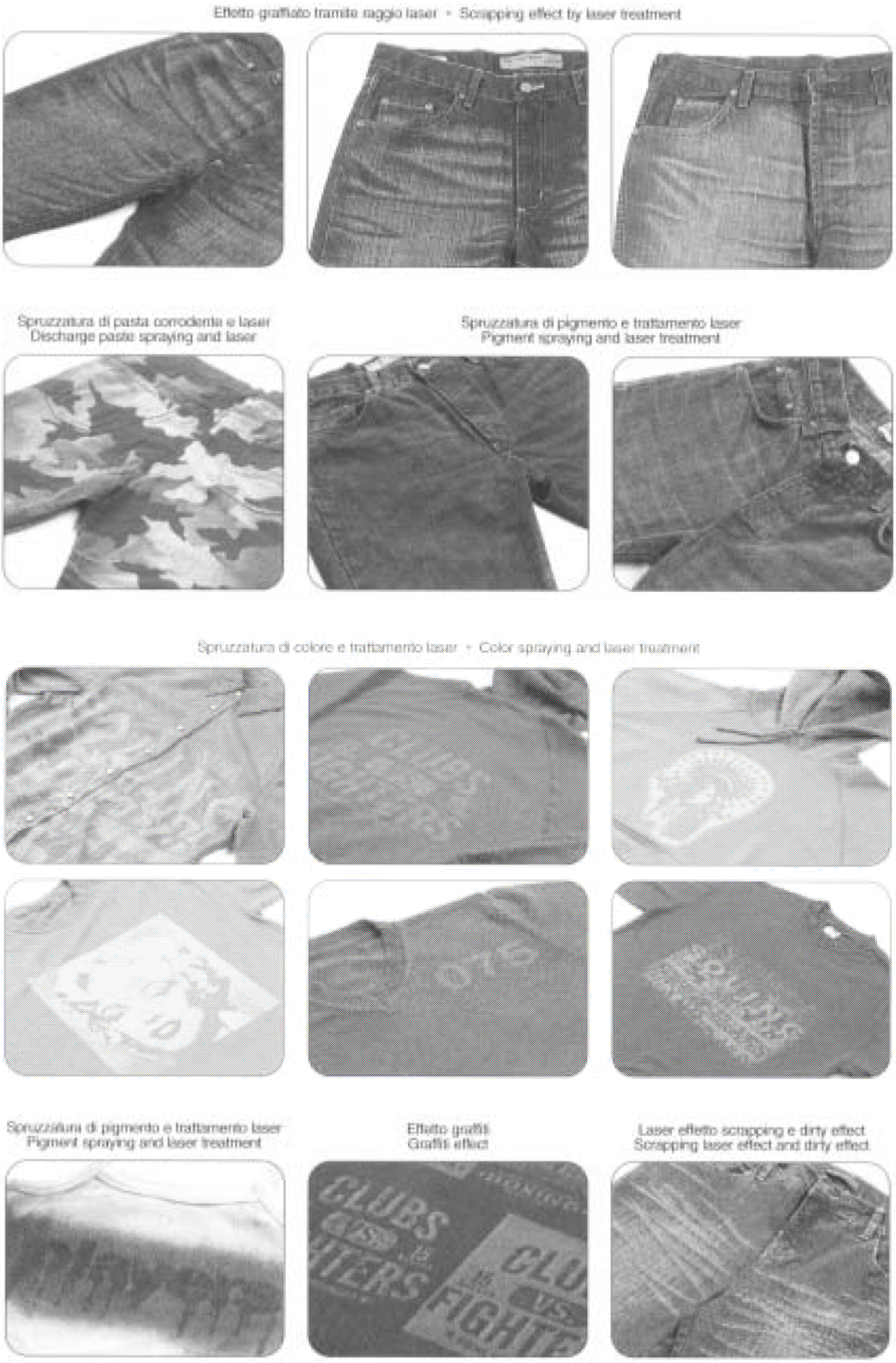
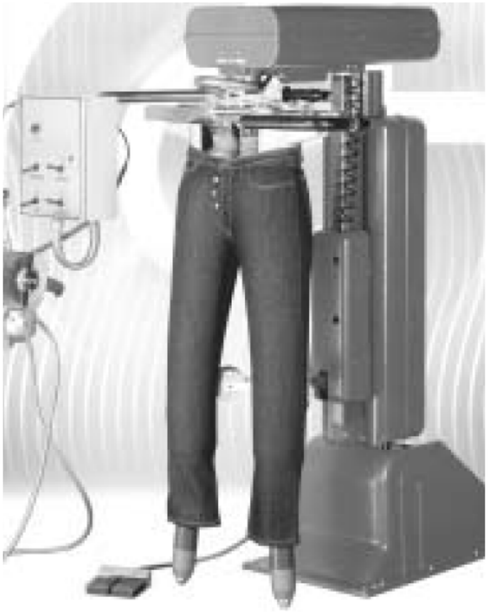


Fig. 204 Effects obtainable on denim garments

Special finishing treatments on denim garments

Manual brushing
The necessary equipment is composed of an inflating system pumping air into a dummy dressed with the garment to be treated. The operator brushes manually the garment without any use of pumice stone or of chemicals.



Figs. 205a and 205b Manual brushing machines

Mechanical brushing
The equipment used for the automatic brushing of ready-to-wear garments consists of robotized machines. These are anthropomorphous robots provided with a pincer, on which various types of brush can be loaded following an automatic procedure. The equipment has several stations (dummies) partly in working position and partly in loading/unloading position, mounted on a revolving cam columm which ensures absolute precision in garment positioning.

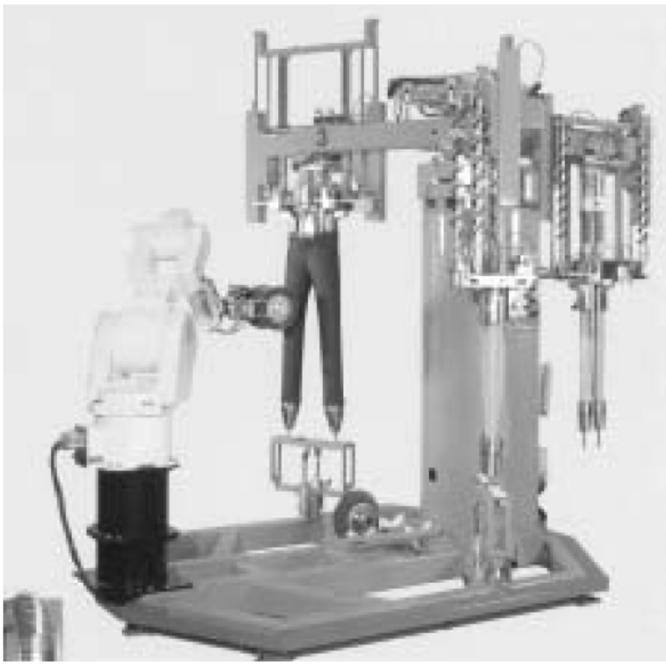


Fig. 206 Automatic brushing machine

Laser treatments

The laser treatment machine is a machine, in which a laser beam focused on the fabric degrades the applied colour; thus a shade depth variation is obtained and the most fanciful and original images and effects can be superficially reproduced.
The final effects depend both on the power level of the laser beam and on the penetration degree of the colour into the fibres. The main effects obtainable on treated garments are:
- scraped effect through laser beam;
- spraying of corrosive paste and laser treatment;
- pigment spraying and laser treatment;
- dyestuff spraying and laser treatment;
- graffiti;
- scraping and soiled effect.

Fig. 207 Laser treatment machine for ready-to-wear garments

Manual spraying and brushing

The equipment designed for the manual spraying and brushing of trousers, jackets, shirts, etc. is composed of a suction cabin and of spraying and brushing accessories.

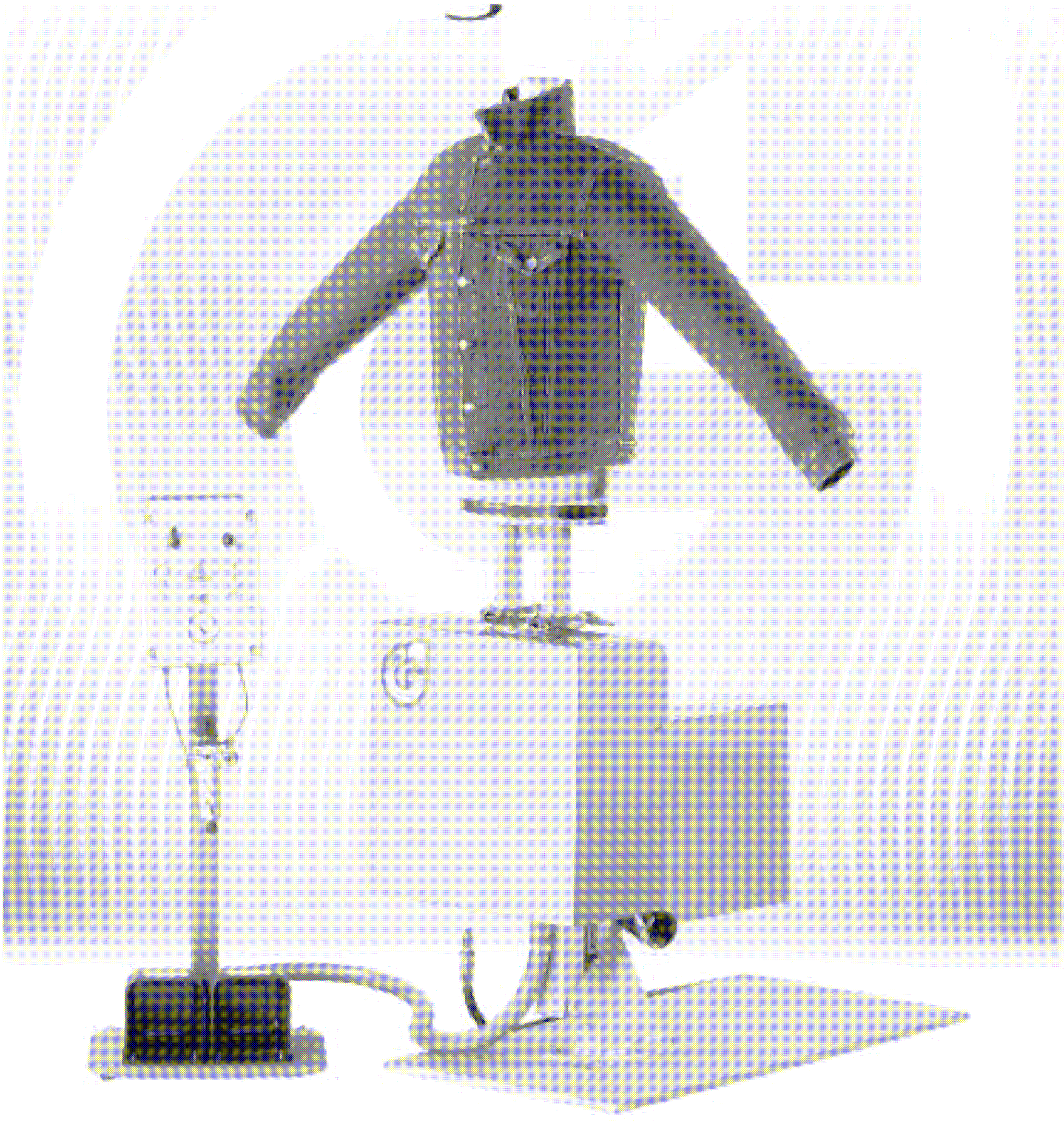


Fig. 208 Machine for manual spraying and brushing

These new finishing typologies of the denim garment, which is generally considered as a "cheap" garment, permitted in last years a radical changement in terms of quality and originality of the denim models, which attained higher market consideration and value in the fashion market.

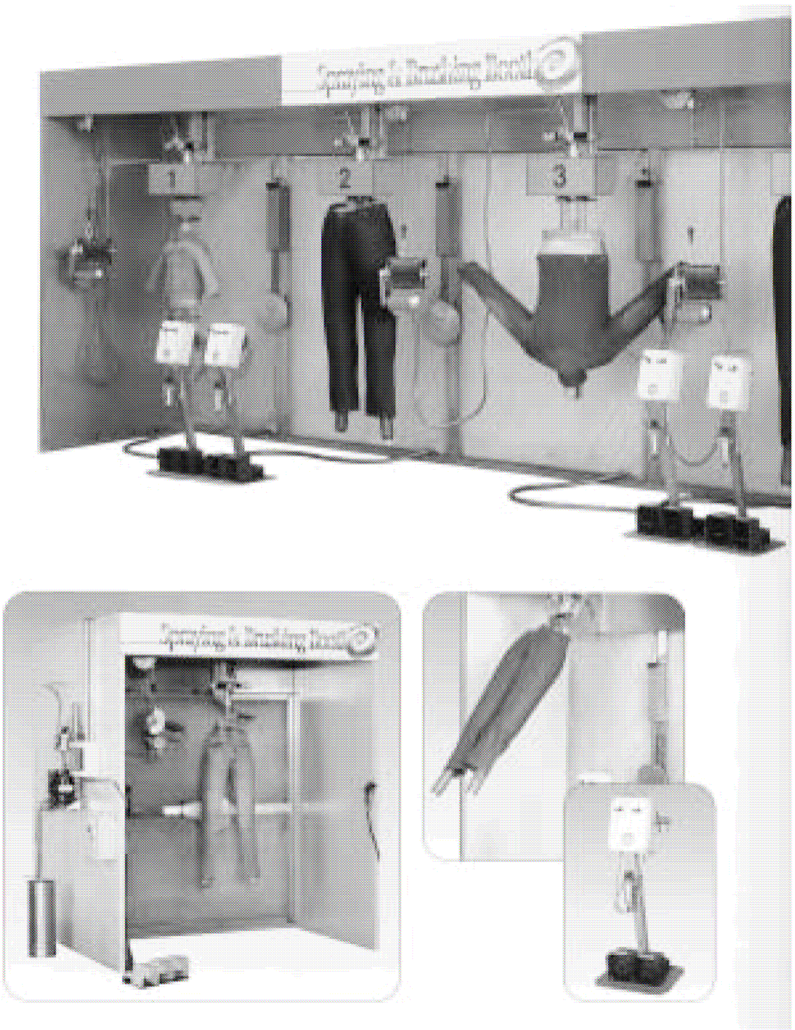


Fig. 209 Equipment for manual spraying and brushing

The influence of finishing treatments on dyed goods

The purpose of finishing treatments is to give cellulose articles and relative blends with synthetic fibres definite properties that are advantageous in terms of use. Nevertheless, we must add straight away that these treatments also cause undesired effects under a double aspect: mechanical-technological (e.g. reduction of strength) or appearance (e.g. colour change and influence on the solidity of tones).
Here we above all discuss the influence that finishing treatments can have on dyeing and prints, though only in general terms as in many cases the problem is linked not only to the type, but also to the quantity of cross-linking agent as well as the method of application and the composition of the overall recipe, which also includes catalysts and additives. It must also be remembered that it is impossible to establish regulations on this subject to generalise dyes by class or certain assortment. Therefore even the following information, which is based on experience gained and the results of many research projects, is only indicative: we therefore recommend that the finisher, for safety reasons, carries out trials under normal working conditions.
The influences of finishing on dyed goods are described in the example of cellulose fibre, but they are suitably adequate even for relative blends with synthetic fibres.

Influence on shade

Dye and print shade can be more or less strongly influenced by finishing treatments, with the possibility that variations in both tone and intensity occur.
Individual dyes as well as finishing products and conditions are responsible for this. The individual cross linking agents on their own are of secondary importance for colour change, meaning that they cause a variance in tone practically the same as the dye itself in most cases, and under similar conditions. On the other hand, the influence of catalysts is entirely different.
The most favourable results are obtained using zinc chloride or magnesium chloride.
Zinc nitrate compromises the tone only in some cases, while ammonium chloride as well as organic hydrochlorides (e.g. 2-amino-2-methylpropanol-hydrochloride) can cause a sharper colour change.
Additives and the conditions of condensation have generally less importance in this regard, nevertheless even these factors should not be entirely overlooked.
Data relating to the influence of the dyes on finishing, often reported on relative colour cards, provides a reference, but does not permit definitive conclusions to be drawn.
It is necessary, in fact, to consider that the environmental conditions of the various finishing mills makes a large number of variants possible, which cannot all be born in consideration on one colour card.
To operate safely, it is therefore necessary that the finisher experiments in his own laboratory to verify which dyes and finishes are suitable for the particular conditions. Naturally, the company who produces the dyes as well as finishing products will always be willing to elaborate on ideal proposals for users.
Even though changes in colour are observed especially when we are dealing with substantive dyes, preliminary trials are also required for reactive dyes as well as for vat dyes (which are less susceptible to the changes in question), in order for the maximum work safety in the mill to be observed.
The trials should also contemplate the dyes that are used for the dyeing of synthetic fibre (e.g. polyester) in blends with cellulose fibre.

Metamerism

By metamerism is intended that phenomenon which causes two objects to present the same colour when they undergo a series of observation conditions, different colours on the other hand under a different set of conditions. In particular, with exposure to light certain dyes present the phenomenon of metamerism, such as some yellow vat dyes. This characteristic is a property of the dye, which cannot be influenced in a positive sense, but it can be accentuated by finishing. Even catalysts highlight the metamerism property of some sensitive dyes and for this reason ammonium salts are strongly advised against, they should be replaced with zinc salts or magnesium chloride.
It is therefore a good idea to try and resolve the problem of metamerism dyes using which are as insensitive as possible for dyeing or printing.

Influence on fastness to light

Fastness to light of dyeing or printing with reactive or direct dyes can reduce in a more or less significant manner the finishing treatment.
In general, the vat dyes are practically uninfluenced with some exceptions, including some leuco-esters which should however always be subject to prior checks.
Given, however, that in practice determining fastness to light implies that time is widely available, it is recommended to use dyes with a high level of this fastness as far as possible as well as finishing products which could affect it only in a very slight way.
Comparing various finishing treatments on dyed goods, it is noted that individual cross linking agents exercise a differentiated influence on fastness to light, even when they are applied without catalysts on dyed goods, that is therefore where a reaction cannot occur. It can be concluded that the catalyst has more or less no influence on fastness to light.

Influence on fastness to rubbing

Fastness to rubbing is affected by determined products mainly in the case of textiles (polyester, acetate) dyed with dispersion dyes.
Of these products, we cite those of preparation for weaving, with winding oils, softeners, and water repellent agents.
Often such a reaction results evident only after a lengthy storage of the dyed goods. Generally, the solidity to rubbing is not influenced by cross-linking agents and catalysts.
Sometimes an abrasion of the fibre is erroneously mistaken for bad solidity to rubbing.
This inconvenience is on the other hand due to an accumulation of finishing products, which can provoke a certain brittleness of the cellulose fibres on the surface of the fabric. To avoid this problem as far as possible, the following should be observed:

- carry out singeing operations with great accuracy, eliminating hairiness;
- avoid bleaching errors, which would provoke deterioration of the fibre;
- use optimal quantities of cross linking agents; in such a way as to avoid provoking excessive brittleness of the fibre;
- keep to ideal conditions for drying after the application of finish and avoid the operation being carried out too quickly.

Influence on fastness to wet treatments

Finishing treatments act favourably on wet solidity (washing, water, perspiration). In the majority of cases, notable improvements can be seen, especially for substantive dyes, for which in the case of light tones the use of cationic products for post-treatments to increase solidity is often unnecessary. On the other hand, a significant reduction in fastness to light occurs.

ACCESSORIES

De-twister rope-opener: this device allows switching from a process in *open-width* form to a process in *rope* form. It automatically eliminates distortions in rope fabrics (woven fabrics, knitted and tubular knitted goods).
A stitch cutting machine (Fig. 210) is usually assembled before this system. This machine opens the sewn pieces of cloth and recovers the yarn. The fabric, placed on a carriage on a rotary plate (Fig. 211), is conveyed to a rope-squeezer (Fig. 212) and then to a de-twister (Fig. 213), which eliminates fabric distortions.

Fig. 210 Stitch cutting machine

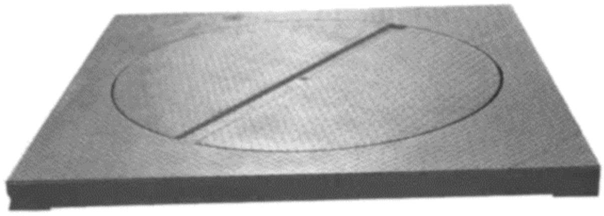


Fig. 211 Rotary plate

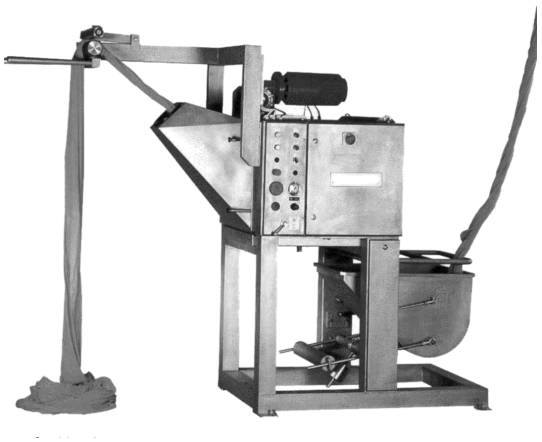


Fig. 212 Rope squeezer

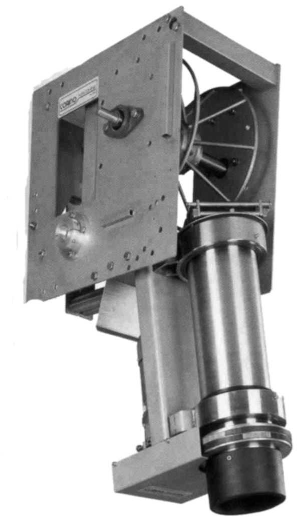


Fig. 213 Special de-twister

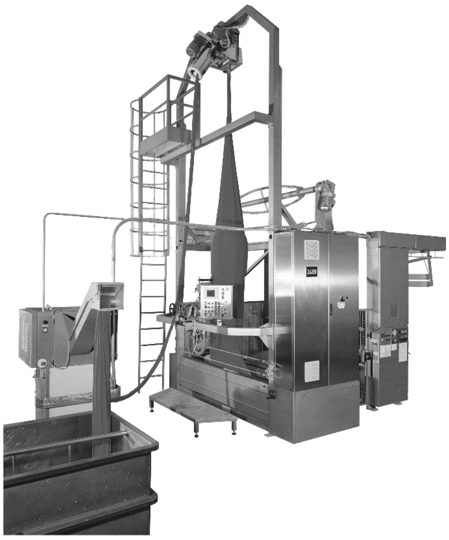


Fig. 214 De-twister for tubular knit

Fig. 215 De-twisting, rope-opening, spreading and centering system

Spreader (centering device**)**: This machine is used to spread fabrics and eliminate the longitudinal creases before loading the fabrics into the open-width machines or before ultimate winding. The spreader can be combined with a centering unit

The spreading process can be carried out by means of bowed bars (Fig. 216), with diverging helical-engraved drums (sometimes combined with oscillating drums) (Fig. 217), with slat-type spreading drums (the slat opening is controlled pneumatically or by means of a servomotor) (Fig. 218 and 219) and with roller drums (Fig. 220).

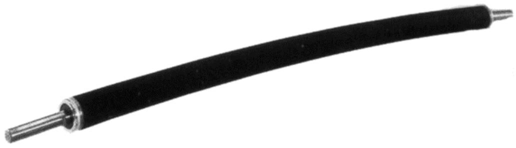


Fig. 216 Bowed-bar spreading

Fig. 217 Helical spreading: photo + scheme

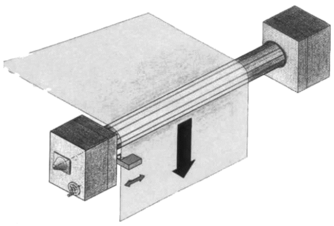


Fig. 218 Stave-type spreading

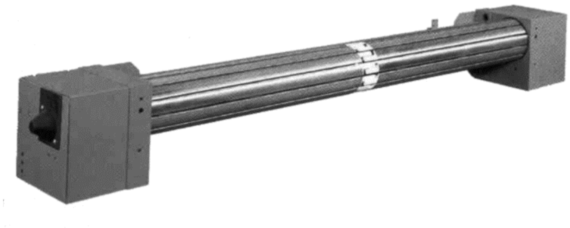


Fig. 219 Stave-type spreading

Weft straightener: This system is fundamental for preparing fabrics for printing and other functional finishing operations before final winding. It allows positioning the weft perpendicular to the warp in woven fabrics (thus avoiding angular differences and distortion), and to line up the stitches in knitted fabrics, as a result preventing the subsequent deformation of the printed patterns or of the finished garments.

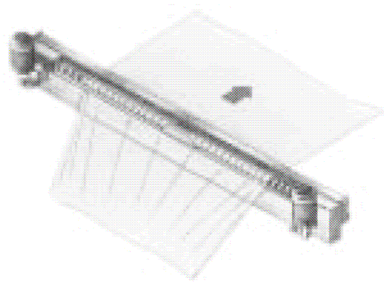


Fig. 220 Roller spreading

Different operating principles are applied to the various types of machines:

- a combination of horizontal or bow straightening rollers (Fig. 221), with manual or automatic adjustment (controlled by photocells and microprocessor or by automatic devices detecting the warp position).
- free wheels with straightening pins (which are used when there is a crosswise difference between the two opposite selvedges).

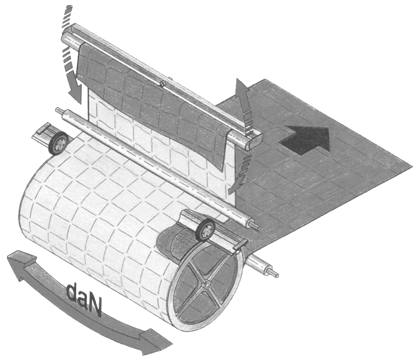


Fig. 221 Bow-roller weft straightener

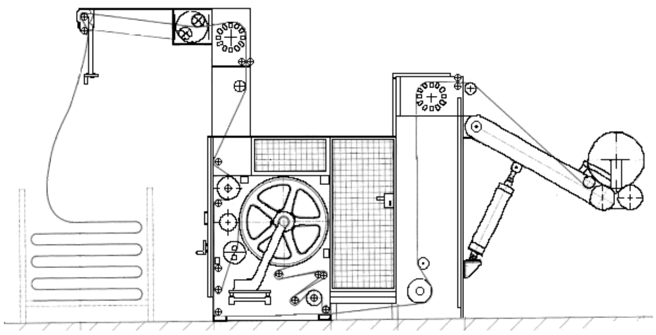


Fig. 222 Free-wheel weft straightener

Cutters: these systems grant an efficient cutting of the selvedge (when required), a precise longitudinal cutting of the fabrics at the desired height as well as the cut and the opening of tubular knitted goods. Cutting systems are usually equipped with gluing or thermowelding systems (for tubular knitted goods made of man-made fibres)

Brushing machines: these systems are used to eliminate any particle or impurity from the surface of the fabric; brushing machines are also used to equalise the fabric hairiness and the direction of the fibre end after raising.

The brushing machine (including motorised drums coated with horsehair) is always combined with an efficient suction system, which eliminates and conveys the particles to a bag filtering system (Fig. 225).

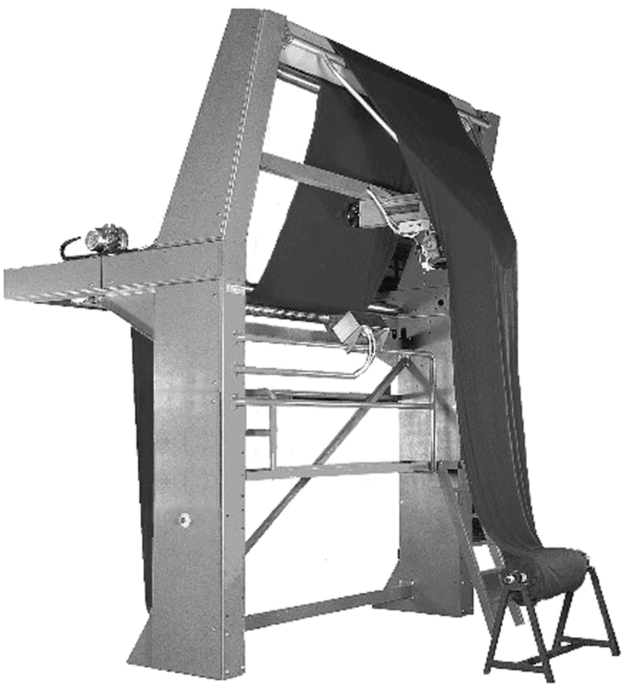
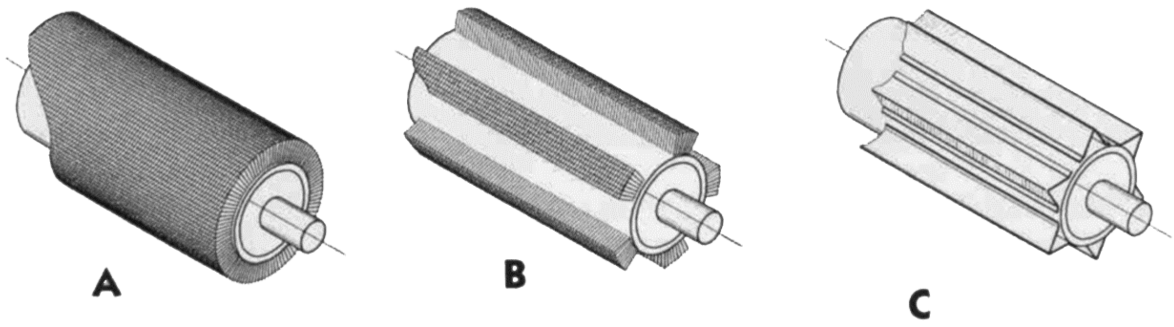


Fig. 223 Cutting, opening and centering of tubular knitted goods



A – Brushing roller *B – Section brush* *C – Beater brush*

Fig. 224 Different types of brushes

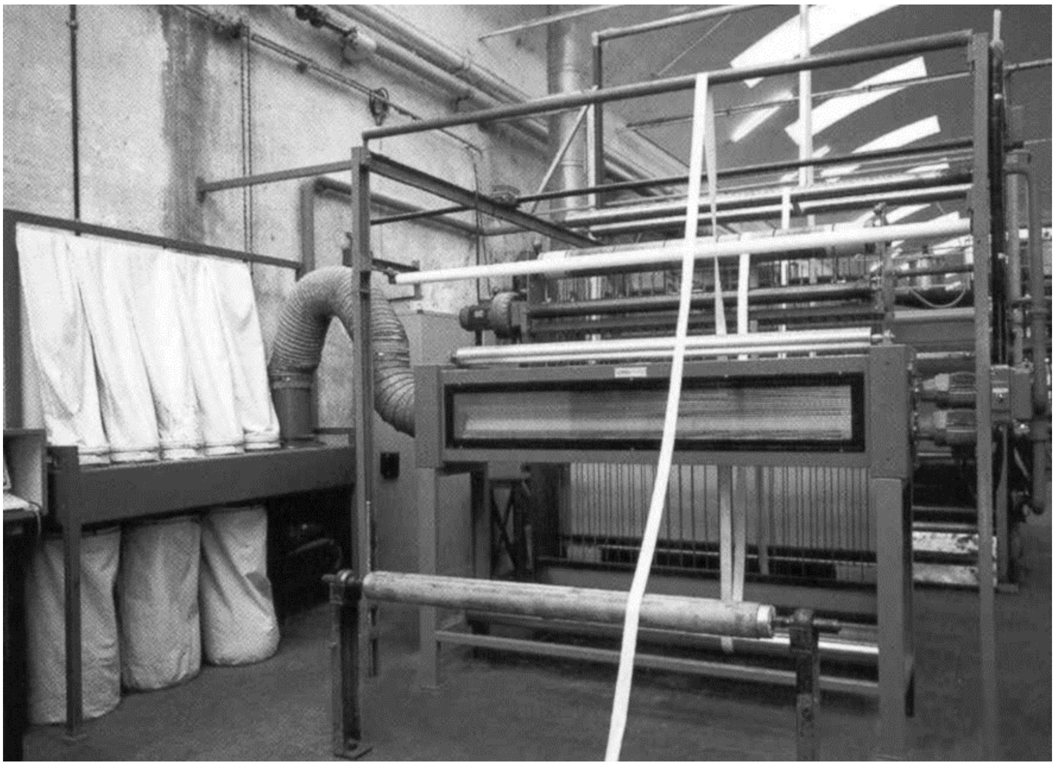


Fig. 225 Brushing machine with suction system

Inspection table: This table is used for the visual inspection of fabrics usually carried out in optimum lighting conditions to allow the operator to detect any possible defects. The inspection takes place at an intermediate stage (usually after weaving) or at the very end of the textile process (final inspection). According to specific needs, the inspection table can be fed by means of standard or giant beam and can be equipped with cutting and packaging systems or with a fabric accumulator (with conveyor belt or others), which eliminates tensions on knitted and stretch goods.
There are many types of automated inspection systems; defects can be highlighted by applying stickers or marking the selvedge; these systems can be also connected to a computer-controlled defect mapping system, granting an extremely precise indication of the defect and allowing cutting optimization.

The controls carried out on inspection tables usually include:

- fabric length
- weaving defects (type and position)
- dyeing defects (type and position) (see reciping, quality control and automation)
- printing defects (type and position)
- seam presence (position)
- anomalous width variations

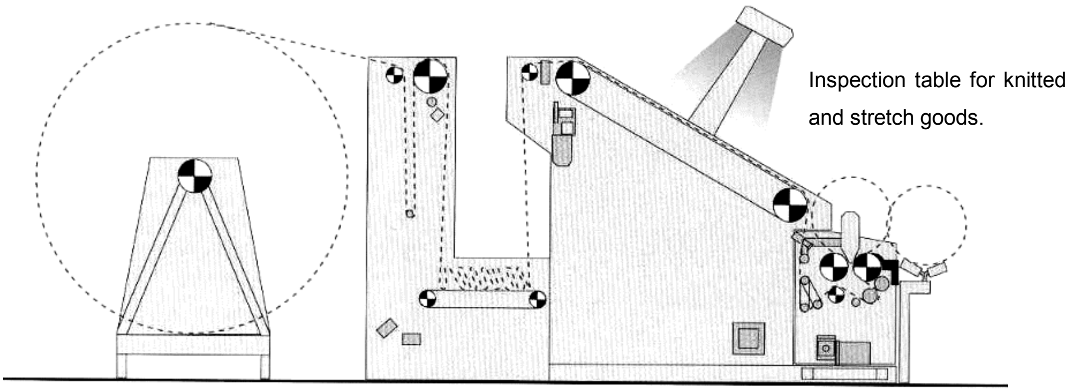


Fig. 226 Inspection table with accumulation belt

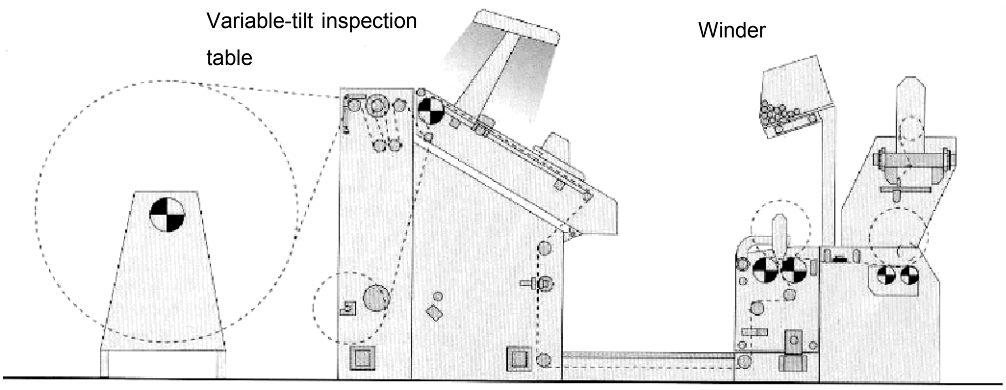


Fig. 227 Inspection table for woven fabrics, knitted and elastic fabrics

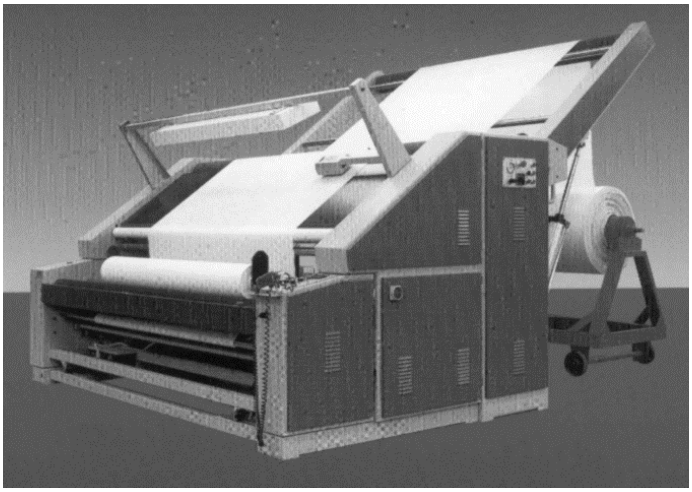


Fig. 228 Inspection table

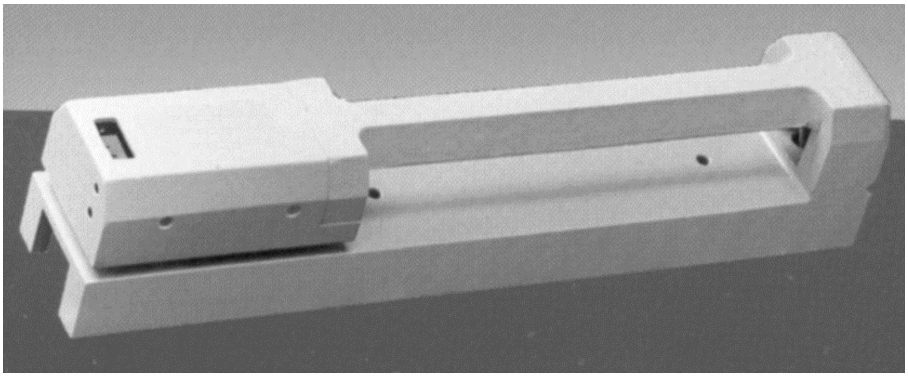


Fig. 229 Meter counting device

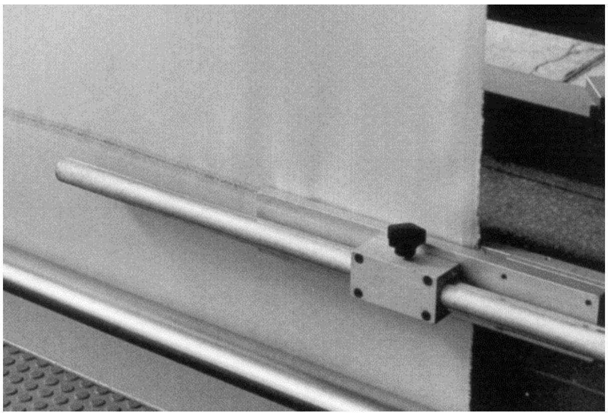


Fig. 230 Seam detector
(through visual indication or cutting)

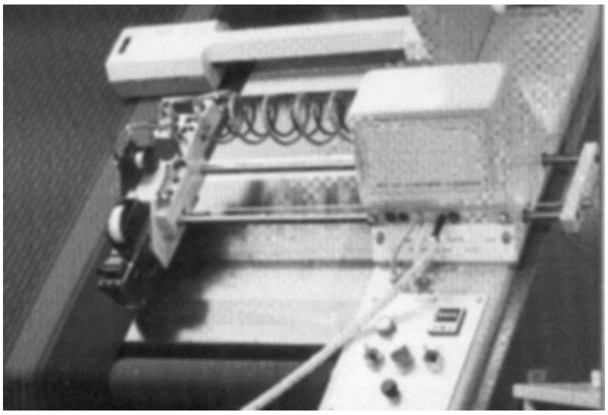


Fig. 231 Defect marking system
with stickers

AUTOMATION IN TEXTILE FINISHING

Foreword

The textile industry is characterized by a considerable fragmentation of the production cycle into a number of segments specialised in the processing of different fibres/yarns; even the single steps are often considerably fragmented, which entails the need for them to be accurately organised in order to guarantee good final results. The first steps of the textile production cycle are less fragmented but fragmentation unquestionably increases during the finishing stage, as a result of the large variety of processes required by the market. Modern automation technologies based on electronics, programmability and smart systems show great potential for textile applications and currently aim to the achievement of major objectives such as flexibility and quality, according to three main evolution paths:
1) the standardisation of components
2) the compatibility of systems
3) the popularity of personal computers.
The standardisation of components takes place thanks to the concentration of automation technologies in some basic types of operations (processes) which must be carried out by the machine. The machine is characterised by a system made of inputs and outputs. Inputs are sensors which transform the physical variables of the system into electrical values which can be read and processed by an electronic unit. Outputs are the actuators controlling the machine and consequently the process (motors, solenoid valves, thermoresistors).
Any process can generally refer to this operating scheme and can be controlled by making inputs operating in relation to the state of the output and following a preset sequence of times. The computer, by means of the appropriate software, supplies the logical links between inputs and outputs and controls the right process sequence.
Through its gradual introduction, automation has affected:
1. machines: the immediate objective was the reduction and simplification of the operator's tasks;
2. processes: the subsequent evolution stage has provided the links between the different production steps with the automatic control of the mill, leaving the operator with only control and supervision tasks. The full integration of the different production areas (inventory control systems, preparation of dyes and auxiliaries, dyeing equipment, material storage, etc) and /or services such as planning, laboratory, design pattern development, technological planning of cycles and production still needs to be addressed. The most advanced integration solutions available today are mainly production cells.

The main difference between automated systems essentially lies in the quantity of variables controlled. Here are the finishing segments most affected by technological development:
1. **colour analysis and control**
2. **process control**
3. **production control systems**
4. **colour kitchens**
5. **automated storage systems**
6. **transport and robotisation systems**
7. **machine monitoring systems**

Colour analysis and control

It is worth remembering that in the past the assessment of colour reproduction was exclusively entrusted to the ability and to the experience of the eye of highly skilled operators working on the colour kitchen, whose judgement, however, could be influenced by a number of physical, physiological and psychological restrictions. The success and the development of electronics have deeply transformed the colour control task thanks to the introduction of new measuring instruments, which have allowed definitely scientific and objective assessment.

All the systems currently available on the market have basically the same fundamental structure and differ only in their performance and in the algorithms adopted for colour analysis. These systems generally feature:

1. a spectrophotometer, which measures the different spectral components of the sample analysed. Today the measurement is carried out by means of a xenon flash, a prism separating the chromatic components and a CCD sensor (of the type used for modern solid-state television cameras that have only a single row of light-sensitive elements or pixels), which reads the intensity of all the components simultaneously;
2. a standard computer, connected to a spectrophotometer like a simple peripheral unit.

The software carries out the processes and defines the functions of the system. It represents an interesting field of competition and makes the real difference between the various systems.

In brief, the software includes the following functions:

- algorithms for colour analysis (processing of the data measured by the spectrophotometer to recognise the colorimetric features);
- preparation of recipes, i.e. the combination of several base dyestuffs to obtain the desired colour by accurately mixing and distributing them; the colour to be matched is suggested to the computer by reading the reference sample with the spectrophotometer;
- assessment of the colour differences, i.e. the assessment of the distance between the colours of the two samples in the colour table, expressed in different systems of coordinates;
- correction of the recipes, i.e. the analysis of the difference between the colour obtained with the machine and the reference colour, and the calculation of dye distributions to improve the dyeing result;
- control and storage of references and recipes for future retrieval;
- control and storage of dyestuffs and textile substrates;
- different types of algorithms to match the colour table to visual assessment and to the type of source used (so that the differences that the human eye has perceived as matching can generate assessments of the same degree);
- selection of the recipe which better matches the sample, the costs and fastness;
- other utility functions.

Automatic devices for the preparation of recipes are now considered essential for all well-organised and efficient dyeing mills.

BENEFITS
Repeatability of procedures
Reduction of sampling times
Reduction of sampling costs
Reduction of dyestuff consumption
Possibility to assess the dyeing efficiency
Impartiality of the assessment
Better control of colour archives
Cost control
Quality improvement

LIMITS
Integration problems
Need for special training
Needs for organisational changes
Need for preparation steps

There are really many reasons justifying the investments in automation which can be carried out at different levels and consequently having different costs; it is worth remembering that even the most sophisticated automated systems applied to any production cycle, turn out to be useless if the information coming from the laboratory is scarcely reliable or even incorrect.
To obtain reliable indications, the laboratory and the production units must first of all be equipped with machines and tools working on the basis of the same operating concept (i.e. the laboratory must be in a condition to reproduce the same operating conditions as during the production process).
With reference to the above-mentioned considerations, it is worth mentioning that manufacturers of colour matching systems have studied the reproducibility of measures, based on very precise and repeatable calibrating procedures. **The dyestuffs must be accurately dosed both in the laboratory and in the dyehouse**. As far as this latter is concerned, no real innovations have been introduced, due also to the high technological level reached by modern automatic colour kitchens; the only real innovations have generated an uninterrupted improvement of the dosing techniques for dyestuffs in different forms (liquid, powder, paste), leading to very accurate results also on large quantities.
The multi-pipette volumetric dosing system is meeting with success in modern automated dyeing laboratories since it eliminates all the residual limits of the standard single-pipette volumetric system.

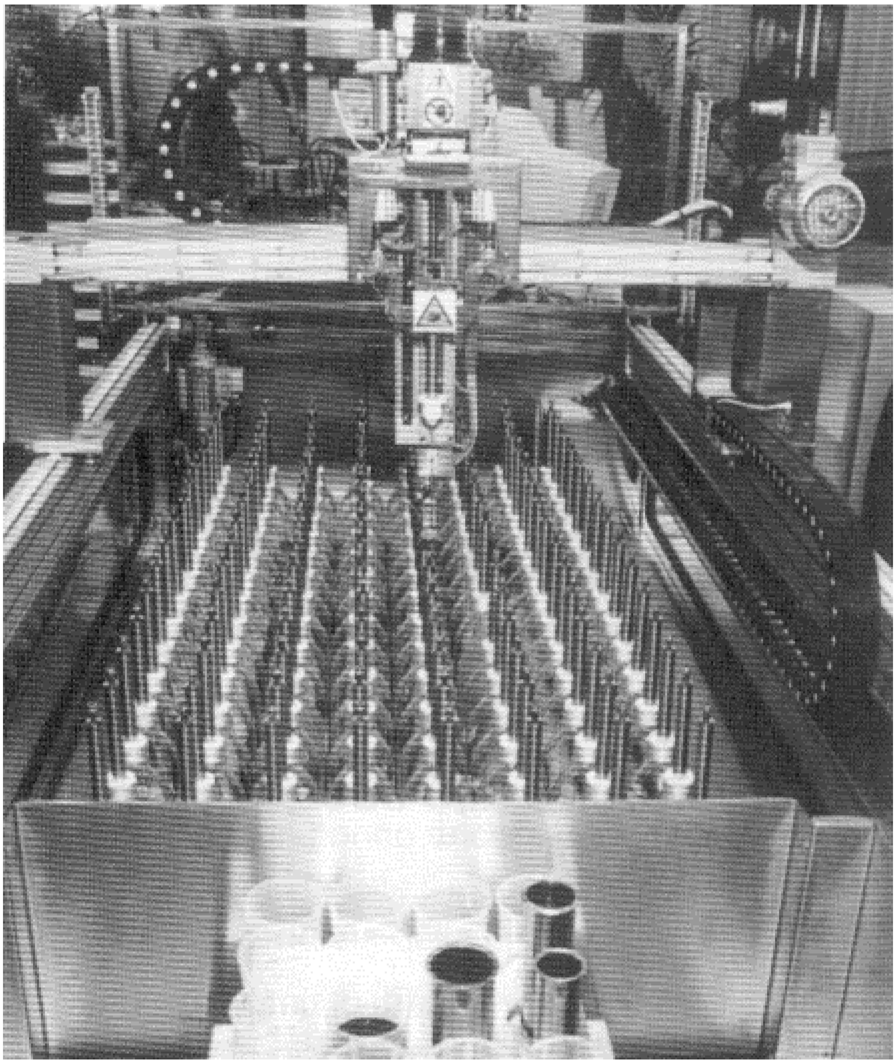


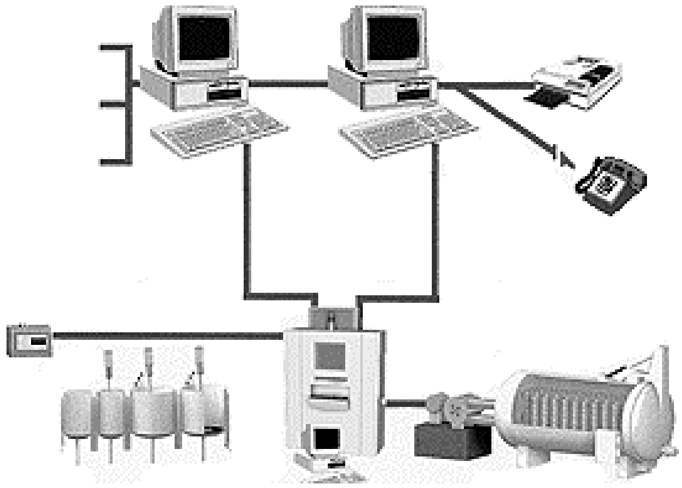
Fig. 232 Multi-pipette sampling system

Here are the main benefits ensured by multi-pipette systems:

1. the elimination of intermediate pipette washing when changing the dye or the substrate, which considerably reduces the operating times necessary for each single dosing procedure and, at the same time, up to a 40/50% increase in productivity (compared to single-pipette systems).
2. the thorough elimination of any residual contamination risk, which could occur in particular with some products and dyes even after accurate washing of the pipette.

Very important also are the benefits deriving from the use of special pipettes studied for the particular properties of some products (viscosity, precision, speed) which give excellent technical results. Another important issue is also represented by the application of a gravimetric system for dosing testing, which completely eliminates any residual doubt concerning the quantities delivered during each single delivery of the pipettes. Operating data are registered by means of a printer, while an automatic self-calibrating system guarantees a continuous check-up of each single pipette.

Process controllers



While process control technology is not as specific as vision technology, it encompasses all manufacturing sectors.

The process controllers relevant to textile manufacturing are basic information-electronic systems that, installed on the machine, control certain fundamental parameters relating to the production process carried out on the machine itself. Essentially, they can be broken down into 4 categories according to the technology of the controller involved, which is itself dependent upon the type of process being controlled.

1. **Cycle programmers**: these are present on many dyeing machines and they are based on the general principle of activating outputs according to inputs. But their actual functioning is more specific: they are pre-programmed to manage a sequential cycle of operations. This facilitates programming, because the only thing that has to be done is determine the sequence of the steps in the cycle and the conditions required for the passage from one step to the next (the reaching of a certain temperature, the expiry of a set time, the arrival of a go-ahead signal, etc.). There exist two types of cycle programmer: one based on a microprocessor whose hardware and software remains the property of the supplier, and one based on a PC- or PLC-fored architecture, which offers all the advantages of standard hardware and flexible software.
2. **PC-driven Programmable Logical Controllers (PLCs)**: these systems are equipped to receive logical information (from switch or pushbutton contacts, limit switches, photocells, any kind of ON/OFF sensor) and to activate logical outputs (electric drives, relay contacts, etc.) A controller checks continuously the status of inputs (openings/closures, presence/absence of electrical current), and according to the configuration of the inputs, activates its own outputs (activated/deactivated, ON/OFF, command presence/absence). The logical correlation between input status and the output status consequently imposed is determined when programming the system. Thus, the PLC can be regarded as a completely general purpose tool, capable of carrying out, when duly programmed by the user, the most diverse functions. In practice, PLCs are used to resolve all those problems relating to automation and sequence management that used to be resolved using electrical systems and relay logics. They feature on practically all the systems used, in textile finishing, for operations such as washing, mercerization, dyeing, drying, calendering, raising, pad-batching and steaming.

3. **Numerical Controls**: these are electronic systems, specifically designed to control the positioning of a number of moving organs (e.g., robot axes). Using special languages, they programme the sequences of the positions of the various axes, each of which is controlled through measurement of the position of the organ. This measurement is carried out by high precision transducers (encoders, resolvers, optical rulers), which transmit to the numerical control a number (hence the name of the system) which represents that position.
4. **Special programmers**, developed specifically to carry out dedicated functions. These programmers are designed with and for the machine, in such a way that input and output signals and processing capacity are kept to the absolute minimum. In order to reduce costs, size and maintenance, they are often engineered in the form of single electronic cards.

The four systems described above are can be integrated with one another, and are often used together.

BENEFITS
Better process quality
Reduction of errors
Greater production flexibility
Rationalisation of the cycle according to scientific criteria
Rapid personnel training
Greater familiarity with production characteristics
Scope for integration with other company information systems
Repeatability of procedures
End quality no longer dependent upon the skill and experience of staff

LIMITS
Need for organisational changes
Difficulty in customizing the system to specific requirements
Difficulty in interfacing with different IT products
Need for assistance and maintenance

Production management systems

The presence, in factories, of highly intelligent, local control systems has favoured the development of production management systems. Nearly all process controller producers also offer surveillance systems that centralise data relating to checks carried out on the machine and allow various levels of interaction.
There is now a very wide range of production management software functions available, and new developments are emerging all the time in various areas as a result of greater contact between software designers and users in the textile sector. These areas include:
- production planning
- planning of production start-up (availability, requirements in terms of human resources and machines, etc.)
- management of dyeing and finishing cycles
- plant and single machine surveillance, remote acquisition and saving of key physical parameters, log record of alarms
- plant and machine synoptic alarms (sometimes interactive)
- records of orders and work carried out
- recipe and cycle sequence management

- management of dyestuffs and auxiliaries warehouse
- statistical analysis of production
- quality control-based classifications
- tracking of single batches, i.e., the keeping of records of the different dyeing and finishing stages so as to make it possible in the future, in the event of disputes or problems, to trace the history of a piece
- link-ups with ERP systems, for the transmission of data relating to technical operations of interest to the accounts department.

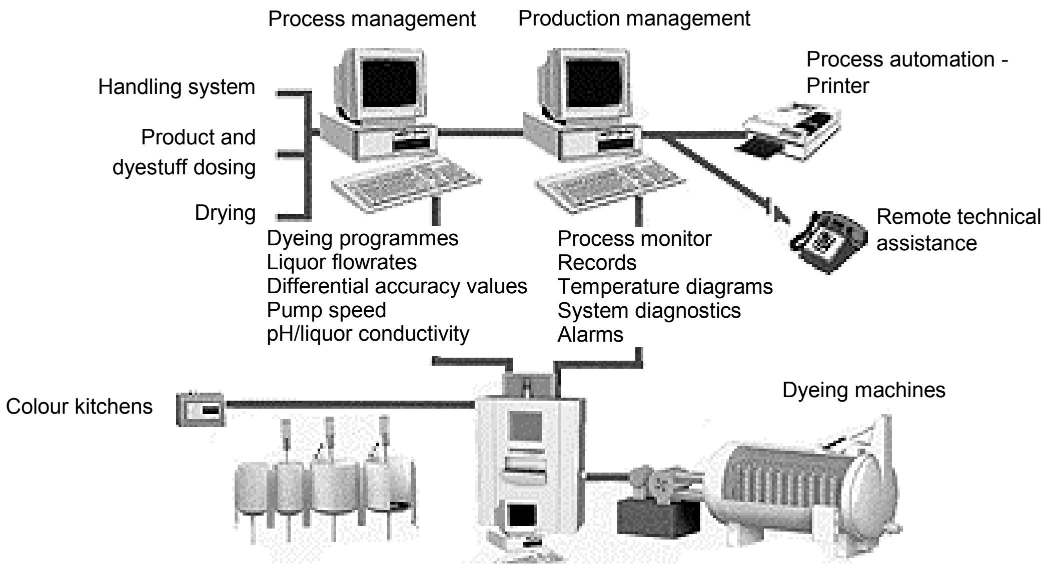


Fig. 233 Example of an open, modular system for the remote control of the dyehouse, which allows the installation of different modules on the desired hardware platforms; the various surveillance modules can be positioned at different points of the system.

The application of information technology to production in the textile sector is similar, in many regards, to its application in most other manufacturing sectors. In particular:

- information technology is taken out of the IT centre, and distributed throughout the mill, making it possible to present/access data wherever they are needed or generated;
- purely administrative functions are supported, more and more, by out-and-out automation functions: management and processing of organisational-type data, but also technological data relating to production;
- batch processes (data processing operations carried out by the computer at the end of which one obtains: balance sheets, production plans, warehouse status, etc.) are replaced by real-time applications, which make it possible, through one of the terminals linked up with the computer, to access and update records immediately;
- there is a growing need to integrate the processing of information relating to areas that are distinct from, but connected with, one another: design, technological definition of processes, machine preparation, planning of resources, etc.

Textile companies want the adoption of IT systems in the production environment to generate a greater and greater rationalisation of management, and to reduce errors and waste. The requirements of a textile company, as regards its information system, can be broken down into three areas:

1. **Company management**: at this level, information systems are needed for the working out of production plans, the checking of results and the working out of sales and cost plans.

2. **Function management**: here, they are required to respond to the need to determine the production plan and flow. In particular, they help in the processing of orders, converting them into processing instructions for individual departments, stages or machines. They make it possible to optimise batches on the basis of resources and technological parameters, even simulating the production chain so as to optimise production speeds and equilibrium workloads among machines.
3. **Process management**: here, they serve to tune the numerous technical regulation and programming procedures that are involved in the production process. In this stage, information systems make it possible to gather all the basic data needed for control and function planning activities.

BENEFITS
Integration of different areas (resource planning, designing, recipe preparation, machine programming, cost control)
Better customer service in terms of order status and delivery times (shorter)
Reduction of errors
Increased company flexibility
Greater control over the company's overall activity
Reduction of stocks
Reduction of downtimes
Process repeatability

LIMITS
Modification of the *modus operandi* (which results in the need to standardise procedures and train staff)
Standardisation problems (due to control systems that are often incompatible with one another)
Poor product customisation

Automated dye kitchens

The problems raised by dye kitchen departments in a dyeing mill are not the same as those raised by the dye kitchen departments in a printing mill, and thus the automation solutions developed for each differ considerably:

1. In **printing mills**, where only viscous fluids (pastes) or auxiliary solutions are used, there are two fundamental requirements: first, to sample the N number of colours per design pattern in the program, and second, rapidly to supply each printing unit with the relevant coloured pastes, in the appropriate quantities: clearly, many samples and products are involved, as are very short execution times. For at least a decade now, systems have been in operation that are able to meet sampling requirements, and that are often used together with other systems that dose print pastes both for sampling and for production. Dosing systems are linked up with a series of containers (which vary considerably in number), each of which is constantly filled with a colour or with a print paste and/or auxiliaries. These containers are connected to the pneumatic or electrical pumps that keep the colours moving and deliver the product to the dosing point. Dosing is controlled by dedicated controllers or PLCs linked up with PCs, which look after recipe preparation and production management. In certain circumstances, the PCs can be linked with a spectrophotometer and with the company management unit.

2. In **dyeing mills**, products used in the preparation of recipes can be in liquid or powder form (auxiliaries or dyestuffs) and dye kitchens usually have four dosing systems with distinct functions:
   a) Dosing of liquid auxiliaries. Liquid products are measured using volumetric lire counters, solid-state gauges or scales. The system doses the product and delivers it to the machine via a single pipe or through a distributor (one pipe per machine).

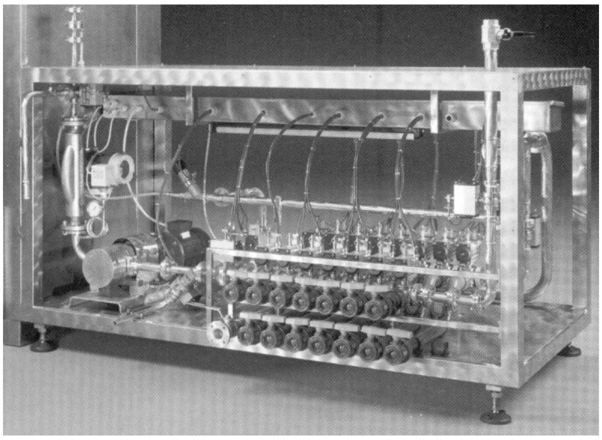


Fig. 234 Liquid product dosing station

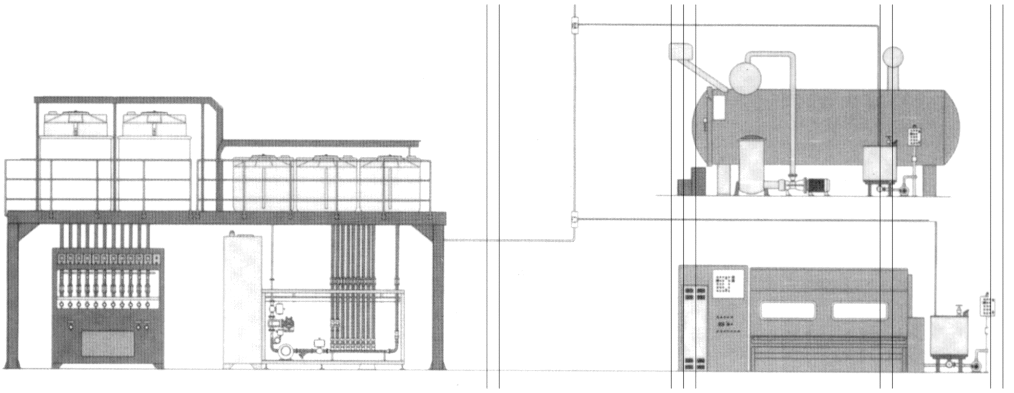


Fig. 235 Diagram of a liquid product dosing station

   b) Dosing and dissolving of solid auxiliaries (salts). Salts are dissolved in small quantities of water (ratio <1:1) and conveyed through a single pipe or distributor to the relevant machines.

Fig. 236 Powder product dosing system

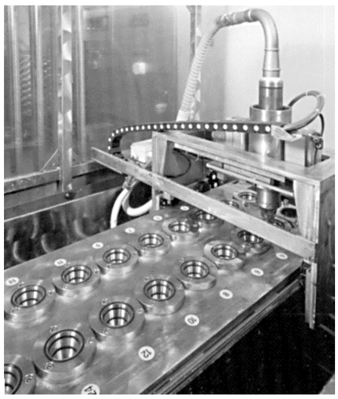


Fig. 237 Powder product dosing (detail of the distributor)

c) Dosing of powdered dyestuffs. The dyestuff is transferred through worms to containers on scales. In dyeing, the use of water-soluble bags is common. These bags are closed after dosing and then immersed in the tank, which is located on the machine. The dosing system is often used together with a traditional dissolving system – this kind of system has a mixer or recirculating pump and the powder is conveyed to the mixer by robot – or a new generation dissolving system (in which the transfer and dilution of the powders occurs by suction, i.e., thanks to the vacuum created in the dilution container).

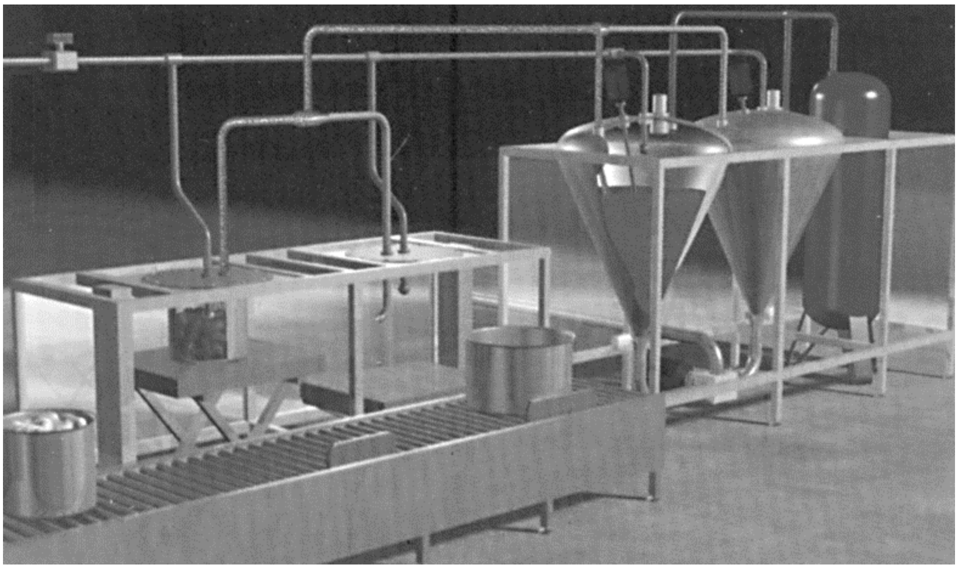


Fig. 238 Dosing system for powdered dyestuffs. In the foreground, the suction and washing station, in the background the dilution station.

d) Dosing of liquid dyestuffs. This is done using machines like those described in point a) or, when greater precision is required, using the dosing technology employed in printing mills.

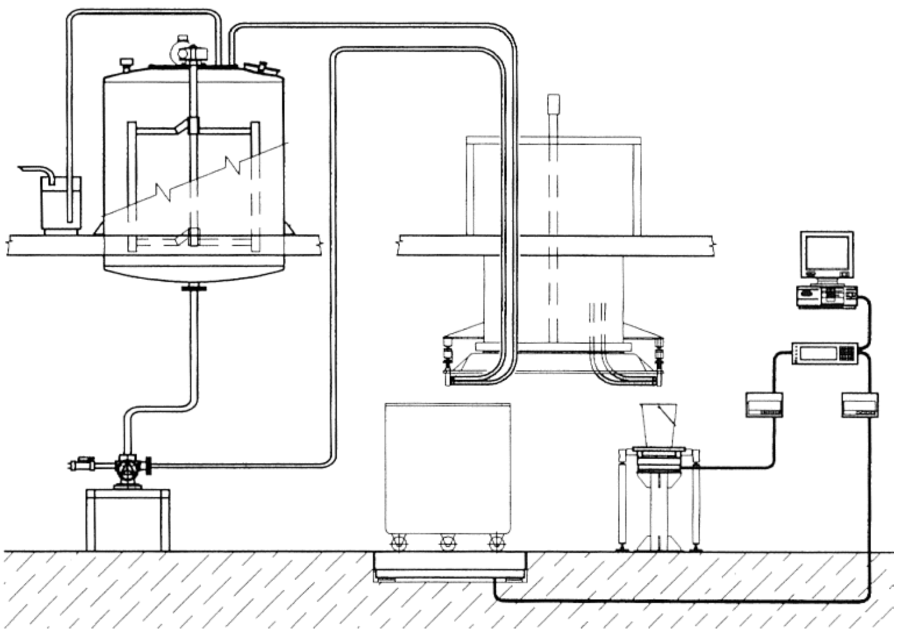


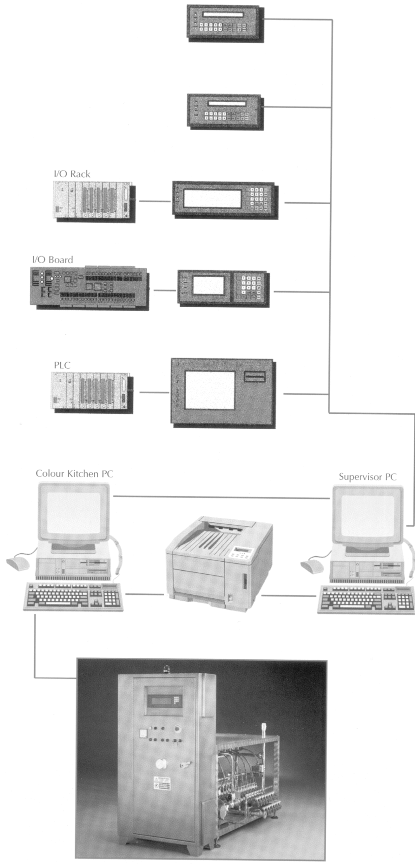
Fig. 239 Scheme of a dosing system used in printing mills

The complexity of truly automated colour kitchens is a result, above all, of the different forms the product can take; as a result of which it is difficult to unify the systems. Weighing, whether of liquids and viscous pastes, or of powders (providing these are homogeneous and non hygroscopic), does not really present any particular problems that need to be solved, but the contemporaneous presentation for processing of products in different forms makes it necessary to have multiple dosing and weighing systems.
In practice, colour kitchens have been created that have dosing systems suitable only for dyestuffs and auxiliaries available in the liquid state, and that weigh the others semi-automatically (or vice versa).
It is important to develop dosing systems that take into account the consumption levels and the contemporaneous demands of the various machines.
The automated kitchen management programs available are generally concerned solely with the transmitting of information needed for weighing, dissolving and conveying to storage tanks, while the timer-controlled feeding and running of the production machines is managed directly either by process controllers located on the machines themselves and possibly linked up with a central system for the storing, management and conveying to the machines of cycle programs (integrated systems), or by operators (semi-automatic systems). Clearly, logical and timely programming of the two stages (preparation of recipes and their use in the dyeing rooms) also needs to be coordinated with warehouse availability (fabrics and products) and central programming.
There already exist fairly simple automated systems for these operations, but here too, when it comes to all the various connections, one comes up against the interfacing problems mentioned in the chapter on recipe preparation systems. In short, it has become essential, as soon as possible, to achieve unification of processor interfaces.

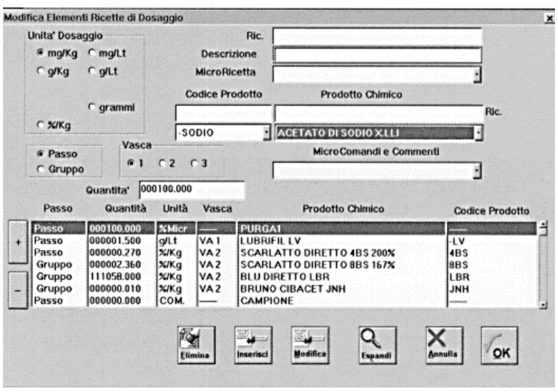
BENEFITS
Reduction of errors thanks to automatic dosing of products
Reduction of waste and downtimes
Rapid dosing
Space savings, thanks to the compactness of the systems
Repeatability of procedures
Better conservation of products in closed tanks and elimination of contamination through contact with the external environment
Improved worker and environmental safety (special exhalation abatement systems)
Reduction of labour due to the elimination of manual operations
Conformity with manual load handling regulations
More rational organisation of labour, greater integration of operational stages and higher engineering level of the dyeing process

LIMITS
Modification of the *modus operandi*
Difficult integration with production methods
Systems not always sufficiently reliable
Difficulty in interfacing with recipe preparation systems.

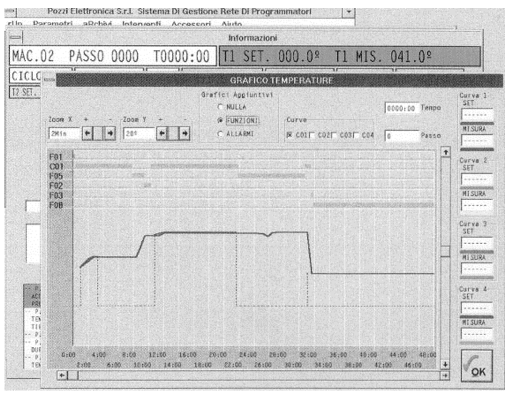
One of the most important technical characteristics that an automatic dosing system must have is, without doubt, the capacity to dose within certain limits. A dosing machine's operating limits are also the safety limits within which it must work; dosing requests at the limit of its capacity must be avoided, as they would lead to a slowing down of the dosing itself and create the risk of operating errors.
Distributed IT systems are meant to allow the specialisation of a system to be combined with the operating ease of whoever is using it; they are not intended to result in the creation of IT cells. In the example illustrated here, an information network connects a series of basic stations that work by means of a single interface and that link up a dyeing room's vital control systems. The operator has at his disposal a record of dosing recipes, which details all the products and order in which they are transferred. Reproducing, with the help of the computer, the procedures normally used in dyeing, he can set the machines according to the required dosage quantities.
Given that a dyeing room may accommodate different types of machine, or machines that carry out various homogeneous processes, it is possible, in the installation stage, to group together the different machines, thereby simplifying their management and reducing the risk of errors.



A PC network system responsible for information storage and system surveillance



Recipes window



System temperature diagram window

Applicative design and studies have led to the creation of compact and modular dosing systems equipped with hydraulic circuits that, using a single pump and distribution line, allow products to be drawn directly from the tanks, measured and conveyed to their point of use. The reading of the measuring, volumetric and solid-state instruments is carried out by a microprocessor connected up in feedback mode with a variable frequency drive that regulates the pump flow according to the programmed dosage quantities.

The level of precision obtained using this system is remarkable: ≥ 50 cc. or ≥ 50 g. with a dosing speed of 30/40 litres/min. The products dosed are conveyed directly to their distribution points, or to pre-treatment tanks for mixing with other products, or for heat treatments, and then via pumps fed into the production cycles.

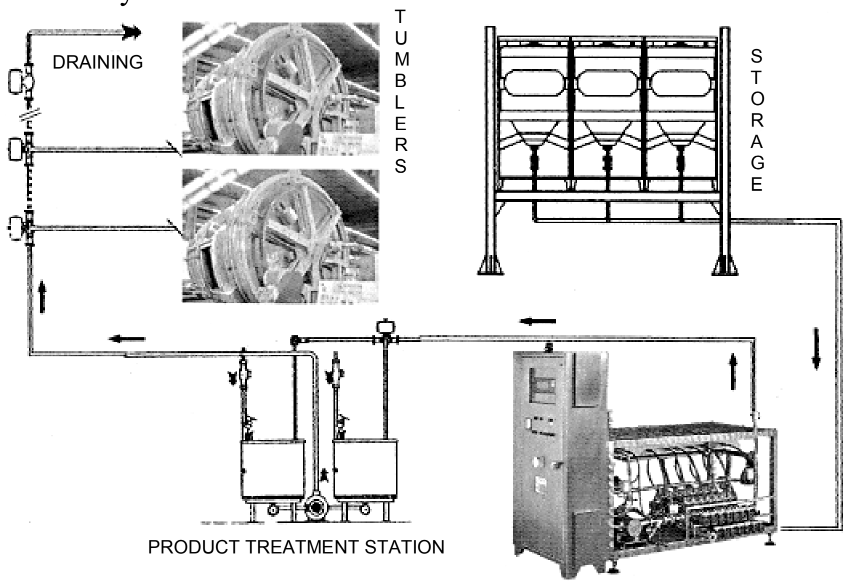


Fig. 240 Compact and modular dosing system

An important new development in the field of powdered dyestuff transportation and dissolving is the vacuum technique, which allows powder to be transferred directly from the weighing bucket to the mixer container, without the use of robots or manipulators. In this way, there is no escape of powder or vapours during the transfer stage as the system is completely devoid of hoods and exhausts, thus meeting all environmental and safety regulations. The speed of powder transfer ranges from 150 to 300 g/s depending on the chemical-physical nature of the product. Thanks to this high transfer speed, combined with the turbulence of the fume abatement water, the powder is subjected to a vigorous mixing action, which guarantees the elimination of germs and the perfect dilution of the dyestuff.
The mechanical action of the agitator combined with the emulsifying phenomena mentioned above result in perfect dilution of the powder in a far shorter time than is possible using traditional methods. Basically, the system is made up of two separate sections. One serves to empty the dyestuff buckets, and the other is made up of dilution containers. The systems are connected together only from an engineering point of view, therefore they do not have to be positioned in a particular way. The suction group can be single or double, as can the battery of dilution containers. The system can be used in-line with an automatic powder weighing system, or more simply, the powder bucket can be placed manually on the surface of the suction section. The pipes and transfer units are cleaned by suction and water.

Fig. 241 Detail of a vacuum dosing system

The solution can be conveyed to the machines by means of a “single pipe” distribution system equipped with sorting valves that, in response to a specific command, divert the flow to the selected machine. The single pipe system offers a number of advantages in relation to systems that use separate pipes for each machine. These advantages include:
- the possibility of setting the quantity of rinsing water delivered to the machine according to the different capacities of the service tanks of the dyeing machine and the relative liquor ratios;
- the possibility of effecting rinsing cycles using limited quantities of water and of reaching speeds and pressure levels able to guarantee perfect cleaning of the line;
- rationalisation and simplification of the operations involved in transfer line installation.

Automated storage

In completely automated systems, the storage, the unloading and loading of fabrics, the insertion and extraction of material carriers into/from yarn-dyeing autoclaves, transportation of materials, control of dyeing cycle parameters and the addition of dyestuffs and auxiliaries are all operations carried out by computer, in the absence of any human intervention.

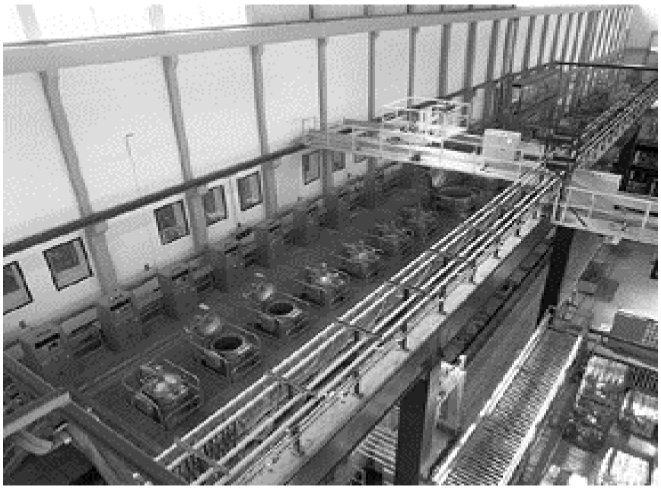


Fig. 242 Completely robotised system for the dyeing of packages, equipped with hoists for the transportation of material carriers and for the loading/unloading of the machines

Warehouse automation is a relatively recent development and it constitutes a blend of various basic technologies: information technology, robotics, handling and transportation systems. Initially applied for the management of large quantities of small items (mechanical and electronic components, medicines, etc.), automated warehouses are now being used with an increasingly diverse range of products.
Because of the strategy of the warehouse, the company’s whole production and organisational system has to be reviewed, and this brings to light three types of flow that, while different, are closely connected with one another, and all three have to be taken into consideration. They are: flow of materials, organisational flow, flow of information.
The warehouse is the heart of the system, around which all these flows revolve.
The type and size of the various inputs/outputs depends on the particular application, but incoming materials can nevertheless be split into two large families:
- materials originating from internal processes
- materials originating from external processes.

In many cases, where production is largely decentralised, the importance of the latter family will be considerably greater than that of the former.
The management system of an automated warehouse involves the digital processing of "opportune characteristics" and the exchanging of information with a host computer, which may be the company's existing host computer, or a different one, dedicated specifically to the warehouse.
The host computer sends the processor lists of withdrawals, destinations, and products being processed, and updates of records, while the processor sends the host computer the list of motions effected.
The management system (warehouse + transportation system) identifies and stores material that has been processed and withdraws materials to be sent for processing, in such a way that the situation in the warehouse can be monitored, second by second, through the creation of a physical map of items and processes.
As far as the textile sector (with all its general and specific problems) is concerned, it is easy to appreciate the growing importance of storage systems, particularly in view of the new organisational systems that tend to cut transit times of products, and whose aim is to guarantee quick service to an ever-changing market, while at the same time keeping no, or minimum warehouse stocks.

BENEFITS
Production cycle integration
Reduction of labour
Elimination of laborious tasks
Space savings
Repeatability of procedures
Reduction of errors
Greater productivity

LIMITS
Modification of the *modus operandi*
Plant and structure layout
Need for preliminary studies and customised solutions
Limited floorspace

Handling and robotisation systems

Automation and information technologies have led to the development of highly sophisticated solutions that allow the problem of handling to be approached no longer with simple mechanical solutions, but by conditioning the company's logistics through "intelligent" flow management that increases flexibility and adaptability.
The basic characteristics of automated transportation systems depend on the applications for which they are destined and on the environments in which they will be implemented, and they are strongly conditioned by the existing layout and structure of the buildings where the systems are housed.
In general, the following systems are found: tracks, ground, aerial tracks, and systems without physical support, or rather that acquire information through magnetic, optical or sonorous guides that do not necessitate any particular intervention on the existing structure of the buildings.
Transportation in textiles is a vast field, and this makes it difficult to provide meaningful examples. In short, it depends:

- on the type of product being transported (staple bales, bumps, comb sliver cans, spindles, packages, fabric rolls, folded pieces, print screens, dyestuff containers, etc.);
- on the type of machine that must connect with the transportation systems (operating machines, control, packaging, warehousing systems);
- the movement to be carried out (simple shifting, inclination of packages, grouping, etc.);

- on the degree of intelligence of the required operations, both on a sensory level (e.g., the capacity to modify behaviour according to the physical characteristics of the package or the environment) and on an operational level (as regards the IT management of articles received by the transportation system, the automatic definition of routes, destinations, etc.).

Practically any transportation problem in a textile company can be resolved through the application of currently existing technologies, adapted appropriately.

One problem that must be solved, if we are, in practice, to exploit automated handling systems in the textile field, is the standardisation of packages and formats.

This is relevant particularly to jobbers, who have no control over the specifications of the semi-processed goods they receive from their customers and on which they are required to work: size and shape of packages, tubes, methods of boxing up, type of pallet for packages and rolls, etc. Another difficulty in the textile sector is the extreme variability of products and the small lots, which mean constant variations in flow and in the layout of the "virtual factory" that is periodically set up within the company. The trend today is to pursue greater and greater integration between transportation systems and the system (robotised or other) in operation at production level, in an effort to provide a flexible solution to a series of problems that emerge in the normal running of the plant. Indeed, a simple system for the physical transfer of semi-processed goods may well eliminate human labour, but it will not improve the company's production flexibility if, upstream and downstream, manual loading and unloading continues to be necessary.

BENEFITS
Greater efficiency thanks to an organisation of labour that is more rational and more coherent with production needs
Reduction of labour costs
Reduction of downtimes thanks to greater production cycle continuity
Reduction of errors
Reduction of laborious tasks
Space savings due to rationalisation of production cycles and layout
Reduction of intermediate storage

LIMITS
Modification of the *modus operandi* as a result of greater standardisation of packages and formats, plant layout and information flows
Rather high labour cost/investment cost ratio
Inflexibility of the system vis-à-vis the considerable variability of the textile production cycle (fashion changes, seasonal productions, etc.)
Difficulty in interfacing with existing machine

In reference to the application of robots in the textile industry, it is worth proposing a system based on the idea of creating an robotised dyeing, centrifuging and drying system, which would receive reels of yarn in special modular columns – the number of packages can vary according to requirements – and then deliver dyed and dried packages in the same columns.

Common to most traditional systems is the tendency to focus mainly on the dyeing stage itself. Indeed, for this particular stage, extremely sophisticated process automation solutions have been developed and the loading and unloading of the carriers has been specifically designed to optimise the operation of dyeing autoclaves.

However, this is often at the expense of the subsequent stages, i.e., centrifuging and drying, even though these, too, are part of the whole dyeing process.

As a result, complex systems have to be developed for transporting the packages from the dyeing carriers to the centrifuging hydroextractor and subsequently to the drying carriers, all of this generating considerable automation or, alternatively, labour costs.

With a view to making the whole transportation system more simple, reliable and economical, special dyeing and drying autoclaves have been developed that are designed to receive the yarn packages in special centrifugable columns. These are transported in modules that take six columns, and they are sent from the dyeing machine to the centrifuging hydroextractor and finally to the drying machine, thereby eliminating the need for specific package carriers.

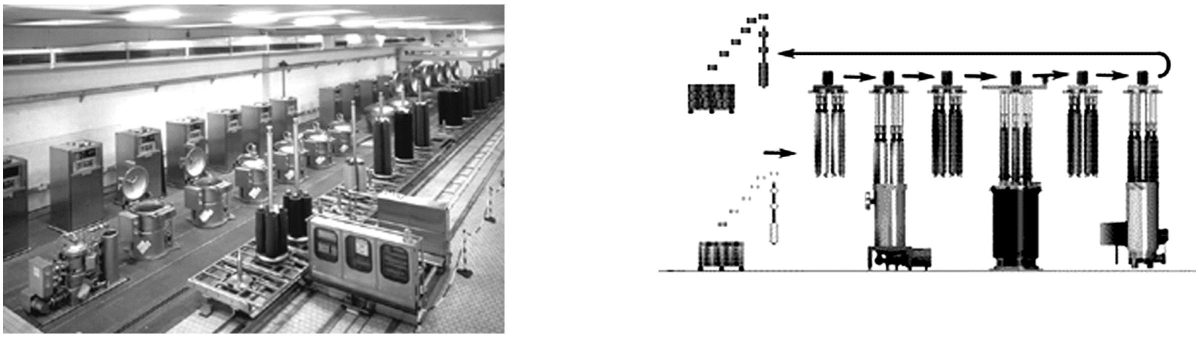


Fig. 243 Robotized six-column module: photo and scheme of cone loading/unloading

The module comprising the six columns is, in fact, moved on a special automated overhead hoist equipped with multiple grippers; this makes it possible, in a single operation, to load the centrifuge to full capacity.
The size and volume of the dyeing autoclave has since been optimised in order to ensure the ideal liquor ratio.
In its most complete configuration, the system is as follows:

- Automatic store of packages for processing arranged on Europallets with cardboard or plastic dividers
- Automatic package depalletisation station, where the packages are loaded and possibly pressed on to vertical, centrifugable package carriers (columns). These columns are arranged on a platform following the ring configuration typical of the dyeing module (a circle of columns whose number is determined by the desired load). The loaded module is electronically weighed at this station.
- The circular modules are automatically lifted and moved (traditional package carriers no longer feature). The robot is an automated overhead hoist with automatic grippers that grasp the upper ends of the columns. The number and the ring arrangement of the grippers correspond to the number and ring arrangement of the columns making up the module; the two rings have the same diameter. They move in a synchronised manner on three spatial axes (X, Y, and Z) in order to move the columns, put them into and extract them from the different machines.
- Fully automatic dyeing units with vertical-axis and dyeing chamber and low liquor ratio. The units use the tried-and-tested air cushion dyeing technique and they are governed by the process computer based on a standard PC platform.Using volumetric reducers, the load can be reduced to a minimum of two columns. The capacity of multiple systems can be reduced, maintaining a constant liquor ratio. This is done by isolating, using special valves, one or more modules; alternatively, modules can be parallel connected, in order to double the load. The system is based on a module of six columns, each column including 12 stacking 2-kg packages. As a result, each column weighs 24 kg and each module 144 kg.
- Hydroextractor that can accommodate the ring of centrifugable columns. The cycle is carried out entirely automatically by the process computer. The centrifugation cycle lasts an average of 15 minutes.
- Dryers with a vertical axis and circular chamber that carry out drying fully automatically with the end cycle governed by the weight of the material. There are normally 2 or 4 modules with a single filtering station, the latter driven by heated air. Since the circuit is open – the air, having passed through the yarn, is aspirated and conveyed to the exhaust stack – the modules can take

yarns of different fibres, counts and colours without the risk of cross-contamination; perfect drying is guaranteed as the cycle end is determined by the weight of each individual module.
- Station where the dyed and dried packages are automatically unloaded from the modules' centrifugable columns. This is the same station that effected the loading operation, and it now places the packages on trucks to be sent for rewinding or, should the packages have to be transported elsewhere, for reloading of the Europallets.

Advantages of the system
- Centrifugable columns on which raw packages are loaded and from which, when finished, they are unloaded, without ever having been touched by human hand.
- Elimination of traditional package carriers
- The same ring configuration is valid for the dyeing unit, centrifuge and drying unit modules; this facilitates the automation considerably and thus increases the system's reliability and reduces costs
- Extreme loading flexibility
- Standardised hydroextractor
- Completely automated links with yarn warehouse.

Machine monitoring systems

The expression "machine monitoring systems" refers to those electronic-information systems that monitor:
- production output, in terms of quantities of semi-processed goods and/or physical events relating to semi-processed goods (number of picks on a loom, reasons for machine stops, number of packages unloaded from a winding machine, etc.);
- operating parameters relating to individual machines (mechanical settings, temperatures, pressure levels, etc.).

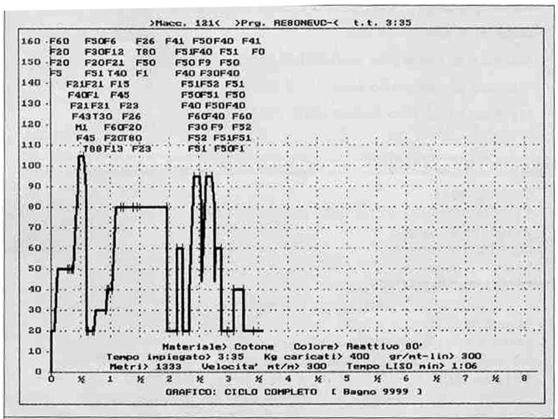
This family normally excludes those systems that control quality on line, and that therefore monitor technological and not purely production parameters. However, the boundary separating the two is very blurred.
The task shared by all these systems is that of monitoring the physical values that can, to variable degrees, be correlated with the parameters that one wishes to monitor, and of allowing data processing in real-time or almost real time.

The actions that follow the data processing can range from a simple signalling to (at more sophisticated levels) self-adjustment of individual machines or of the entire department.
There are, essentially, two different categories of system:
1. **Monitoring of quantities produced and methods of operation.** This category embraces most systems used in companies for the direct monitoring of production methods; it is often not enough simply to monitor the number of single units produced; instead, this value needs to be correlated with the time it took to produce them, with the status of certain fundamental parameters, with events that occurred and with other collateral parameters. Systems belonging to this first category are now present in some considerable number on the textile market, and having got beyond the pioneering stages, they have now achieved high levels of reliability and technical features satisfying the market's requirements. Thus, they can be used for:
   1) real-time reading of machine status
   2) recording and cataloguing of machine events into log reports, also including untimely operator interventions
   3) the statistical processing of the above data
   4) the creation of dyeing cycles and the conveying of the same to the process controllers

5) remote control of the machine
6) planning the activities of the dyeing cell.

All monitoring systems also pilot the automatic dosing systems, acting as an interface with the dyeing machines' process controllers. They are easily added to existing mill equipment, without the need for complex mechanical or electronic adjustment operations. This clearly facilitates their installation. As regards their processing capacities, they are easy to personalise and often offer performances that are superfluous to effective information needs.

2. **Monitoring of department operating parameters.** The systems belonging to this category are ones that not only monitor, but also regulate machines that are dissimilar to one another but employed in a single setting. This function is usually achieved through the use of special processors and software procedures that can rarely be applied in exactly the same way in different production organisations. The monitoring of a dyeing room, or of a printing room, constitutes a good example, as here the production and management variables are complex as they are linked to machines that differ from one another. There thus arises the need for simultaneous management of different processes, involving different physical parameters. Systems belonging to this second category, when installed in finishing departments (dyeing, printing, wet and dry finishing), are rarely designed and created by the manufacturers of the individual operating units, precisely because they are designed to manage machines from different suppliers: this is thus the sphere of intervention of companies specialising in system integration.



Medesimo diagramma di tintura eseguito su Multiflow Ht dotata di vasca di preparazione (fondo scala fisso)

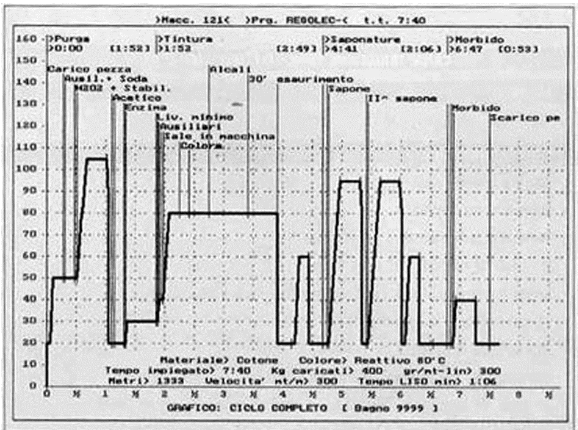


Diagramma di tintura di partenza su macchina Ht standard

BENEFITS
Improved quality and customer service
Reduction of machine stops thanks to better programming, organisation of labour and preventive maintenance
Increased productivity
Reduction of staff for checking tasks
Greater availability of real-time information that can be compared automatically and continuously
Improved planning in terms of quality, quantity and organisation
Possibility of carrying out preventive maintenance, thanks to the statistical analysis of data

LIMITS
Incompatibility with other information systems
Installation costs for replacement of microprocessors and for the development of software interface with existing controllers

FINISHING TERMINOLOGY

Substrate	This is the basic fabric, ready to be subjected to finishing treatments in order to acquire the effects, properties and characteristics which contribute to form the "finished article".
Article	This term indicates the finished fabric, namely the fabric ready for sale and make-up into a "ready-to-wear" garment.
Item	Is the definition used for the garment ready for sale.
Finishing	Is the ensemble of the operations which trasnsform a textile substrate into an article. This definition may appear simplistic, but is sufficient to define the finishing of the fabrics designated for sportswear and leisure wear. Finishing contributes to produce a certain handle, is made up of certain affects and has well defined properties.
Handle	Is the conventional identification of one or more finishing treatments. It recalls in most cases the effects and the characteristics of the finishing treatment, but is often identified simply through a trade or brand name.
Labelling	Labelling indicates properties and characteristics of a finishing treatment through values or symbols expressing the result of real controls carried out according to international regulations (UNI, DIN, ISO, etc.) or according to procedures agreed upon between the parties. The indication on the label of the washing instructions of the item, as well as of its fiber composition (percentage/type of fibre and chemicals), is compulsory by law. Performance and colour fastness values can be shown also on the label applied on the article and on the made up garment.
Reference sample	This is the demonstrative sample of the main characteristics of the article. It is distributed during the exhibitions to the potential customers.
Coupon	This sample is by far larger than the reference sample. It is requested on the occasion of exhibitions and is sent immediately to the customer to enable his prospective purchase and sample-pieces order.
Sample-pieces	These correspond with the article and count for future orders. They are used for making up the items required for sales promotion at wholesale dealer's and warehouse level. The sample–pieces have to be delivered a few weeks after the closing of exhibitions. In the past the previsions about the quantity in meters of the future orders was based on the number of ordered sample-pieces in a ratio of about 1 to 10.
Coordinates	These are various articles which together contribute to form a complete outfit (e.g. shirt, waistcoat, jacket). It is obvious, that the articles which have to form a coordinate must show strictly constant dyeing, handle and dynamometric properties.
Lab-Dye	This term refers to the laboratory reproduction of a special colour not comprised in the colour card considering its tone variation due to wet and

dry finishing operations. The Lab-Dye is the standard reference for the production lay-out.

WR This term, which recurs increasingly in the finishing sector, means water-repellent or drop-resistant.

Quality control This is today increasingly entrusted to third parties, that is to qualified and certified service firms, such as the "Codetex" company, which classify the produced items according to the different selection classes until declaring them as unmarketable on basis of the defects found on 100 linear meters (faults) and of their dynamometric properties. A piece of fabric will be classified as first choice when the faults per 100 linear meters do not exceed a number of 10/15; in case of fabric for sportswear, especially resin coated backings, the tear strength values (Elmendorf tester) must not be less than 600 g in weft and 900 g in warp. This applies to garments to be made up with buttons and buttonholes, whereas the requested tear strength values go up respectively to 900 and 1200 g in case of garments to be made up with snaps.

Trend This is an abstract term, which is however very important in the sportswear sector. It recurs in following slogans: to set a trend, to buck the trend, to scent the trend, to change trend, to be on the trend, the trend leading the fashion. Trend means in these cases guideline and involves colours, finishing treatments and fabric composition. It is important, as it considerably affects the sale results and the success of an article.

Sample-book This is a set of articles presented in an orderly and proper way in order to arouse the interest of the potential customers and to favour their sale. It is the backbone of the participation to a fair, in terms not only of substance of the proposed articles, but also of the form in which the articles are presented (aesthetic combination, typical properties, etc.). An orderly collection must always include "standard" ready-made garments, at least in the case of the most valuable articles or of the new articles to be launched. The making-up of these garments is a very important aspect, to the point that sometimes it brings about the success or the disappearance of an article from the market. For the making-up of "standard" garments for exhibitions, it is recommended to entrust this operation to specialized companies and to take advice from a professional stylist.

Collection This term is used to indicate the contents of a sample-book, but is more properly used to define the set of made-up garments which is meant for a fashion show or for sales promotion purposes.

Creative director The creative director is the leading figure in the modern textile industry which is focused on the international markets through active presence in the major textile exhibitions. The creative director has high sensitivity, is able to perceive trends and is gifted with good taste and style, abreast of the task of preparing every year the company's operational basis, namely the "sample-book". He chairs the meetings aimed at selecting substrates, finishing treatments and final products. He therefore leads research and sales activities as well as the commercial organization; in few words, he embodies the company image.

DYEING TERMINOLOGY

Liquor ratio This term indicates the ratio between the weight in kilos of the material to be dyed and the total volume in litres of the dyebath. It is in short indicated as LR. A liquor bath 1:30 means in the laboratory practice the use of 30 ml liquor per each gram of textile material.

Shade depth This term expresses the dyestuff quantity in grams used for 100 grams of textile material. If not otherwise specified, similarly to the colour cards of the various producers, the quantities of dyestuffs, water, auxiliaries, etc., are always referred to the weight of the material to be dyed.

Bath exhaustion This term indicates the quantity of dyestuff transferred on the fibre from the bath during dyeing; it is expressed as percentage on the dyestuff quantity existing in the bath at the beginning of dyeing. A bath is considered as completely exhausted when it reveals an exhaustion level of 100%.

Levelling A dyeing is considered as levelled when the textile material does not present, in its various zones, any variation of the dyed effect. Levelling depends primarily on the dye migration power, that is on its capacity, after mounting on the textile substrate, to distribute itself uniformly along the fibres.

Stripiness This term indicates the particular defects of dyeing unevenness which can appear in a textile product in form of more or less large stripes or bands with a repeat frequency depending on the single case.

(Hank) turning With this process, hank-material to be dyed is adequately handled and moved in the dyebath in order to attain the best results in terms of level dyeing.

Dye Stripping This process has the purpose of removing a dyestuff from the fibre by means of proper chemical or mechanical treatments.

Re-dyeing This operation subjects an already dyed textile article to a new dyeing process with a dyestuff suitable to enhance the lustre of previous dyeing or to change its tonality. As an example, a sulphur dyeing can be re-dyed with a basic dye.

Sampling This operation reproduces a shade through a tinctorial process, by delivering a shade which is matching a certain sample.

Shading Shading has the purpose of shifting the tonality of a given dyeing colour towards the desired effect through addition of proper quantities of one or more dyes. For instance, if we shade a red colour with various quantities of blue, we can obtain a certain range of violets. The shading technique is of paramount importance for sampling.

Textile auxiliaries This term groups together all products affecting directly or indirectly the dyeing process. They can be divided into following categories:

a) Acids
Acids promote dyeing with acid dyestuffs, as they characterize positively the amino groups of proteic fibres.

b) Salts
Salts can act as levelling agents, as in the case of sodium sulphate in wool dyeing, or as promoters of bath exhaustion, as it happens, again using sodium sulphate, in cotton dyeing with direct dyestuffs. Some salts find on the contrary application as reducing agents for the dissolution of certain dyestuffs: an example is the use of sodium hydrosulphite and of sodium sulphite respectively for vat and sulphur dyes.

c) Bases
The most used bases are caustic soda and ammonia: the first product is indispensable for the solubilization of naphthols and for vat dyes reduction, while the second product is used to produce low alcaline baths.

d) Surfactants
1) Non-ionic – Anionic surfactants
These surfactants contain type $–CH_2$-CH_2-O chains and are not ionizable. They are widely used as detergents, levelling agents, dispersing agents.

2) Non-ionic – Cationic surfactants
These surfactants are compounds in whose molecule the cationic character is associated with the non-ionic character. They find application as dispersing agents and as levelling agents, in particular in wool dyeing with some types of acid and pre-
metallized dyestuffs.

e) Swelling agents or carriers
These aromatic compounds permit a certain swelling to highly hydrophobic man-made fibres, as polyester.
It is assumed that their action, which is determinant in the dyeing of said fibres, permits to form on the textile substrate a film which acts as solvent towards the used (disperse) dyestuff. This way the fibre comes into contact with a more concentrated solution of dyestuff, and consequently a rise in dyeing speed takes place.

NOTICES ON LABORATORY TECHNIQUES

Textile wetting before dyeing

Goods must be accurately soaked in water before being introduced into the dyebath. If the textile is made up of already bleached cellulosic fibres or of man-made fibres, it should be left dipping in water at 50°C for 10-15 minutes. If on the contrary the textile is made of raw cotton or of scoured wool, it is recommended to let it boil in water for some minutes, better if in the presence of some drops of a suitable wetting agent.

Bath preparation

The necessary quantity of dye solution is introduced into the dyeing vessel, which in the simplest case can consist of a glass beker with 250 ml capacity or, better, of a cylindric container in stainless steel or porcelain which is heated in water-bath or in glycerine-bath. Heating with direct flame should be avoided as much as possible, as it prejudices temperature setting.
The needed quantities of water and auxiliaries are subsequently added and finally the goods to be dyed are introduced into the bath. This technique is however applied not in all cases because, as we shall state later on, auxiliaries need occasionally to be added, partly or totally, after goods introduction.

Dyeing operation

During the whole dyeing time, the textile should be subjected as much as possible to turning, to avoid that it piles up; bath volume must be maintained constant through frequent hot water additions.
In order to prevent stain formation, goods shall be temporarily taken out of the bath when in the course of dyeing additions of dyestuffs or auxiliaries are required.
As soon as the operation is completed, the textile shall be thoroughly rinsed (provided that further treatments are not advisable) and finally dryed in moderately warm current of air.

Textile goods

During dyeing trials it is advisable to use as package for the fibres skeins of about 5 g weight.
The use of fibres in form of staple or of tops does not permit to control whether a sufficient levelling has been attained, whereas the dyeing of fibres in form of fabric implies, if it is carried out in simple laboratory vessels, quite a lot of practical difficulties.
If dyeing trials on various blended fabrics are necessary, it is preferable to make up out of them at least 1 cm long stripes for each different yarn in order to enable detecting even the smallest differences in the final dyeing effect.

Water

It is advisable, at least theoretically, to use distilled or purified water, but it is often possible to resort to common tub water, provided that it does not exceed 10 degrees of French hardness.
Should distilled or purified water not be available, then suitable sequestering agents of Ca^{++} and Mg^{++} shall be added, as for instance phosphites, namely compounds derived from phosphoric acid which are characterized by a high dispersing power preventing flocculation and peptisation. Thanks to this property, they find wide application also as post-dyeing soaping products, in particular with reactive dyes.