# DYEING

The dyeing process is aimed at giving woven or knitted fabric its intended colour, crucial to its ultimate use.
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 piece.*
When the dyeing process is carried out during the first processing stages, for example on staple fibres, a better colour fastness can be achieved; bulk dyeing refers to the system used to dye a staple fibre before it is spun, this process is carried out in perforated baskets and although there may be areas where the dye does not penetrate completely, in subsequent spinning operations these areas are mixed with the thoroughly dyed fibre, thus ensuring an overall even colour.
Yarn dyeing is carried out after the fibre has been spun into yarn. Yarn dyeing is preferred for manufacturing Jacquard or striped fabrics; this dyeing method grants a good colour fastness since the dye penetrates the fibres and reaches the yarn core. Skeins are dyed in hanks, spools are dyed in autoclaves and warp yarns are dyed in perforated beams loaded in autoclaves.
Piece dyeing is carried out on several types of machines and the material can be open-width or rope dyed. A good dyeing strictly depends on different parameters and conditions that can be evaluated immediately (such as good consistency of the dye and repeatability) or which require specific fastness evaluation (manufacturing, use, dry or wet processing) that can be controlled only by means of subsequent laboratory tests.
The machines used are chosen according to the material to be processed. The crucial requisites are the following:

- protection of the substrate
- repetitiveness of the results
- cheapness of the process (depending on process time, machine automation degree, liquor ratio, cost of the products used and wastewater purification).

To carry out a dyeing process it is necessary to:

- Dissolve or disperse the dye in a water bath (with manual, semiautomatic and automatic colour kitchens according to specific preset rules).
- Feed the dye solution in the machine after suitable filtering (automatic colour kitchen, supplementary vats, pumps and filters).
- Transfer the dye from the liquor to the fibre (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 the dye has mostly transferred onto the textile to be dyed, distributed homogeneously, well 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 (pad-batch wetting). The dyeing liquor is distributed homogeneously onto the fabric (i.e. also the dye is distributed homogeneously).
In a second stage the dye penetrates into the fabric and is then fixed. At the end of the process the material is washed.

Some operations must be carried out for both exhaust or pad dyeing:

- dissolve or disperse the dye in water and filter.
- achieve an homogeneous contact between the dyeing liquor and the fibre.
- make the dye penetrate into the fibre.
- fix the dye in the core of the fibre.
- 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 the 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 good dyeing uniformity and consistency (the process is affected by operating temperature and time).
During the process, kinetic and thermodynamic reactions interact.

**Dyeing Theory** (exhaust dyeing)

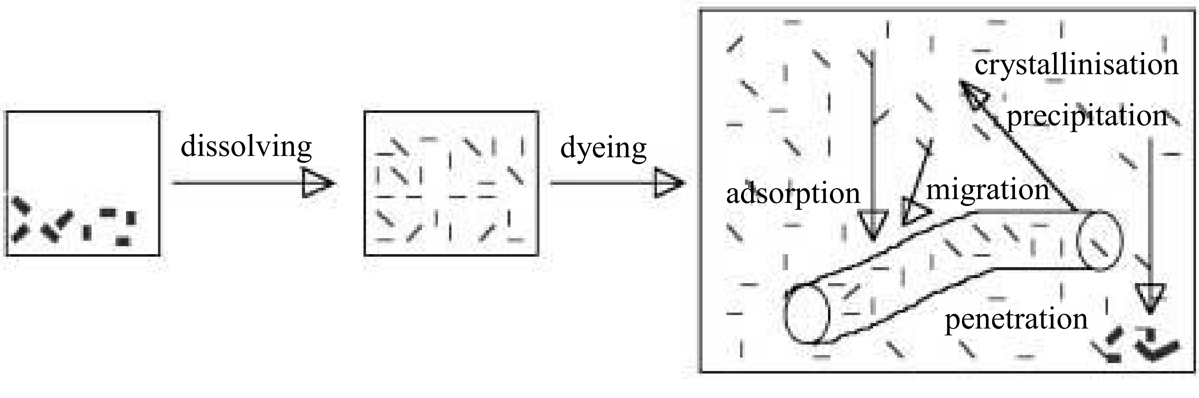
The dyeing process is a chemical reaction occurring between the dye and the fibre:

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

We can examine both the kinetics (process speed) and thermodynamic (balance) relationships.

**Kinetics and thermodynamics applied to dyeing**

The dyeing process is in reality a complex chemical reaction, which occurs between the disperse dye and the fibre immersed in the solution. This process is carried out at different process stages (Picture 34):

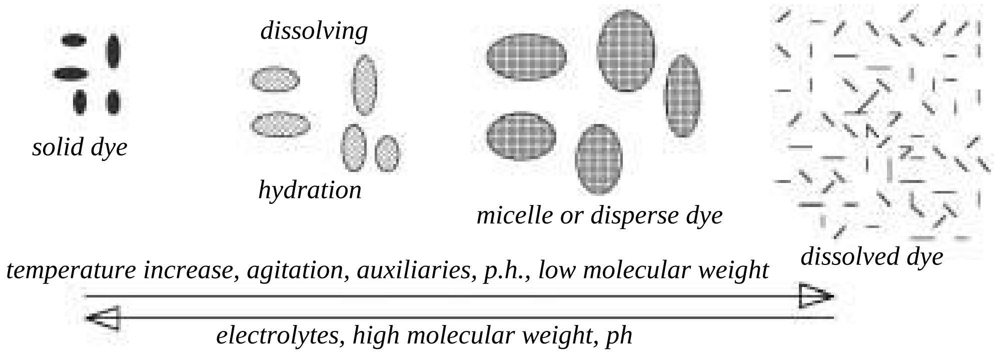



*Picture 34 - Dyeing process steps*

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 reaction balance).
Hydrokinetics (influence on kinetics of the liquor and/or material turbulence, depending on the dyeing machine used). This is an important aspect not only for exhaust dyeing.

**First stage** (dissolving and dispersion of the dye)

In this first stage, the dye, in solid form, is equilibrated according to the dye dissolved in molecular form or in micellar form (aggregates of many molecules with good solubility), or in form of dispersed micropowder (microcrystals of dye molecules poorly soluble) (Picture 35).




*Picture 35 - Disperse dye solution*

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 dyeing agents, made of sodium salts from phenols, carboxylic acids, sulphuric esters, metal groups, or, most frequently, from sulphonic acids;
- cationic dyeing agents, 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 a balance 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 quantity of hydrophilic groups: dyes with large-size molecules (high molecular weight) are generally poorly soluble; the presence of a bigger quantity of ionic groups (sulphonic), or the simultaneous presence of hydrophilic groups (hydroxyl, amino, amide, etc.), increases the solubility with the same molecular weight. An increase of the temperature allows a quicker achievement of the balance 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 considerable 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 (by the effect of 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 (intense shades dyeing, poor LIQUOR RATIO) favours the aggregation in micelles. The speed established for the balance between solid dye-micelles-dissolved dye (in standard dyeing conditions) is generally sufficient to produce no effect on the dyeing speed.
Unsuitable conditions can cause precipitation and therefore different colour shading or reduce the exhaust of the dyes.

b) Disperse dyes have an extremely reduced solubility (0.05-50 mg/l), which increases proportionally to the temperature. A balance between dissolved and dispersed molecules is anyway produced (dispersed molecules are covered with a coating made of dissolving 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 dissolving agents increase the stability of dispersions, which are generally more stable at pH 4-5. Excessive agitation (mechanical breaking of the coating of dissolving agents), temperature variations (breaking of the bounds between dissolving agent / dye or dissolving agent / water), long stay-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 dissolving agent, in bigger crystals, with a subsequent increase of their size and their precipitation on the fibre and in the liquor.

**Second stage** (adsorption)

During this stage, by the effect 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 auxiliaries) affect the thermodynamic interactions (a) and therefore the balance of the reactions, thus determining the exhaustion degree of the dyeing liquor.
The same factors influence also the rising speed of the dye and therefore its smooth dispersion. Obviously this can partly affect the dyeing speed, which, during this stage, is also affected by hydrokinetic factors connected with the machines used (b).

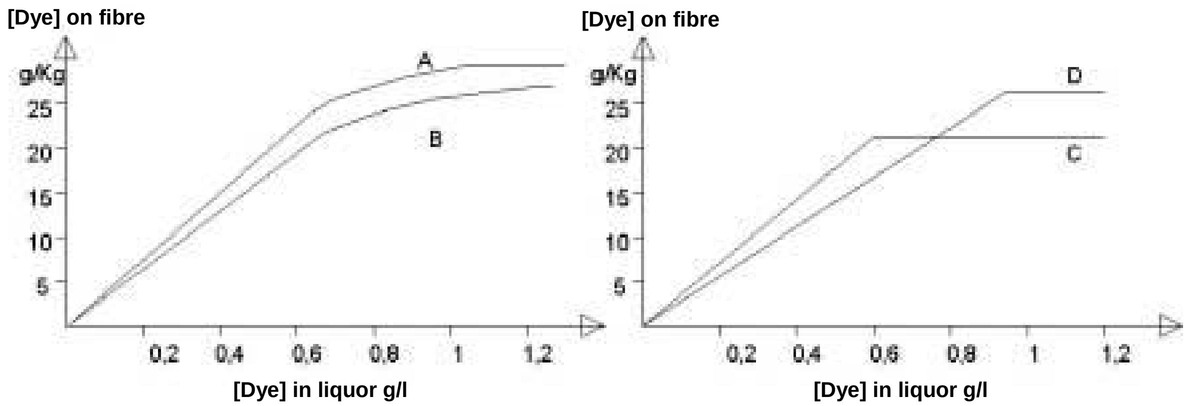
a) The affinity between the dye and the fibre is the ability of both dye and fibre to form a permanent bond. The greater the affinity, the stronger and higher are the fibre-dye bonds and the smaller is the dye for the solvent (water). Generally it is also directly proportional to the molecular weight (molecular size) of the dye. Affinity is therefore a condition strictly related to the chemical composition of the dye and the fibre. As far as thermodynamics aspect is concerned, the same above mentioned criteria must be applied and in general an increase of the dyeing temperature causes a change of the balance towards the solution dye, with a reduction of the exhaust, and therefore a reduction of the dye-fibre affinity. In particular for disperse dyes, considering the Nernst distribution coefficient:

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

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) increase 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 and more intense colour shades can be obtained), but the dyeing balance changes towards the solution dye, thus reducing the exhaust degree 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 greater quantity of bonds with the fibre and therefore, by effect of the temperature increase, they exhaust liquors more deeply and more quickly than dyes with a lower molecular weight.

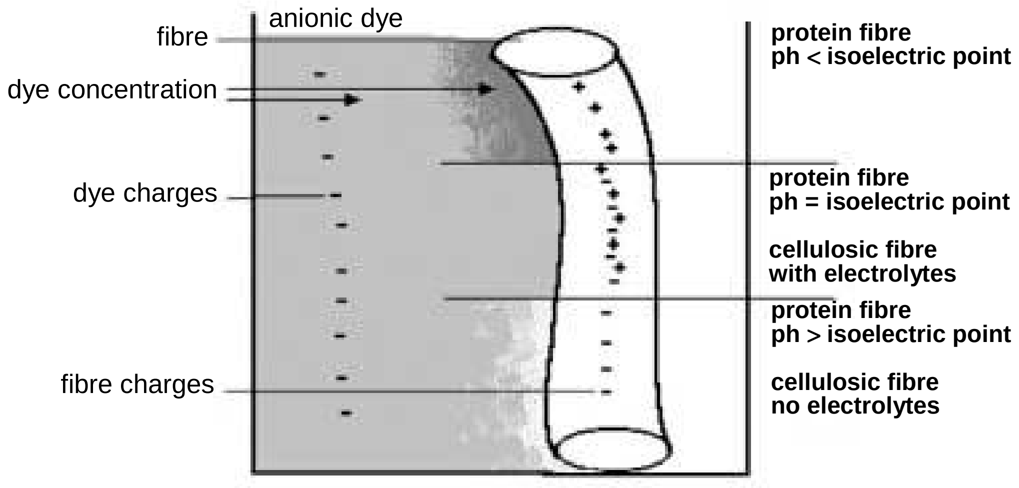
*Graph 1 – Balance between the dye on the fibre and the dye in the liquor*




**IONIC DYES** **DISPERSE DYES**

| **Curve** | **Balance conditions** | **Line** | **Balance 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 |

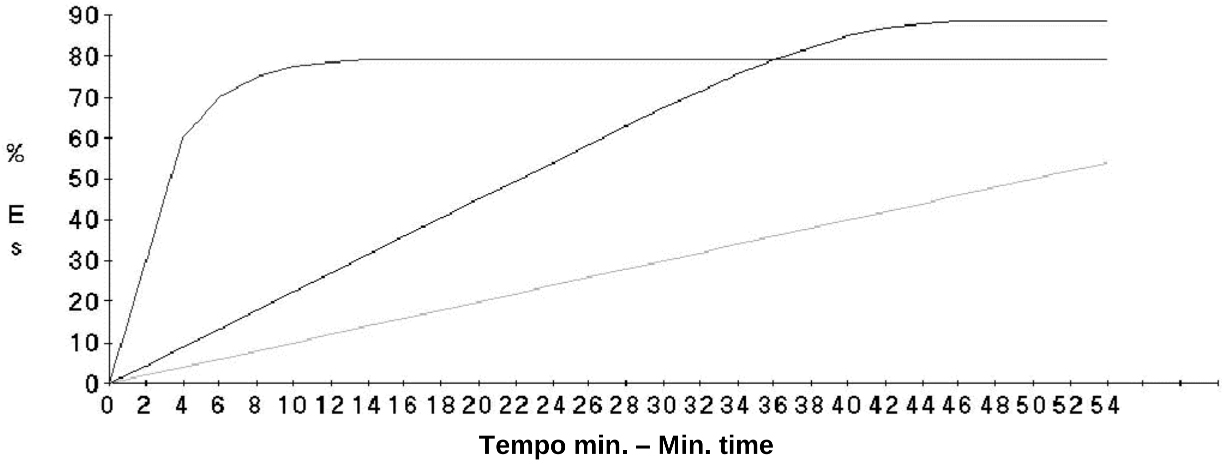
For ionic dyes:
- Amphoteric fibres (wool, silk, PA) below the isoelectric point have positive charge, with an increase of the affinity towards anionic dyeing agents; at pHs corresponding to the isoelectric point they have zero charge, while above the isoelectric point they have negative charge and therefore reject dyes; this allows an accurate control of the affinity and consequently of rising speeds and dye exhaust, by suitably adjusting the pH value. (Picture 36). For cationic dyeing agents the affinity changes in the opposite direction to the one described above.
- Cellulosic fibres in zero charge environment take negative electrostatic charges, thus reducing the adsorption of anionic dyeing agents; by adding electrolytes to the solution, the adsorbed cations can neutralise negative charges on the fibres, thus facilitating the adsorption of the dyes (Picture 36).




*Picture 37 - Dye concentration in the liquor near 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, opposite to the disperse ones, the saturation point of the fibre is reached gradually, and therefore the relationship between the dye concentration in the liquor and on the fibre is no longer linear.
  High temperatures reduce the dye-fibre affinity and also the exhaust (Graph 1 - C, D curves), but the adsorption speed will be higher (Graph 2)

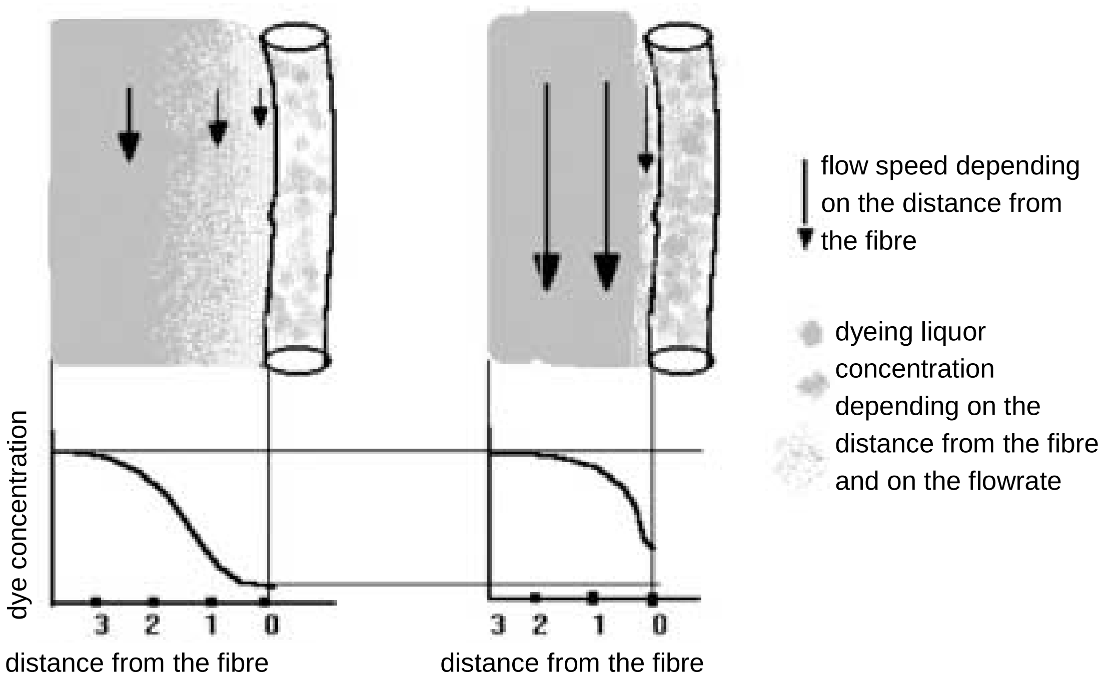
*Graph 2*




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

During this step the exchange between the material and the liquor, and therefore the hydrokinetic condition, are crucial factors (consequence of the motion of the liquor and the material to be dyed).

The most favourable conditions are created with machines where both the material and the liquor move and 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 reducing the adsorption speed. A correct speed of the liquor change in contact with the fibre allows the maximum concentration of the dyeing solution near the fibre, and consequently the correct speed. (Picture 37).
At the same time, the liquor flow in contact with the material is spread homogeneously and allows a good 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 it must be slowed down or adjusted (T°, pH, auxiliaries) on optimum values to avoid an irregular distribution of the dye.

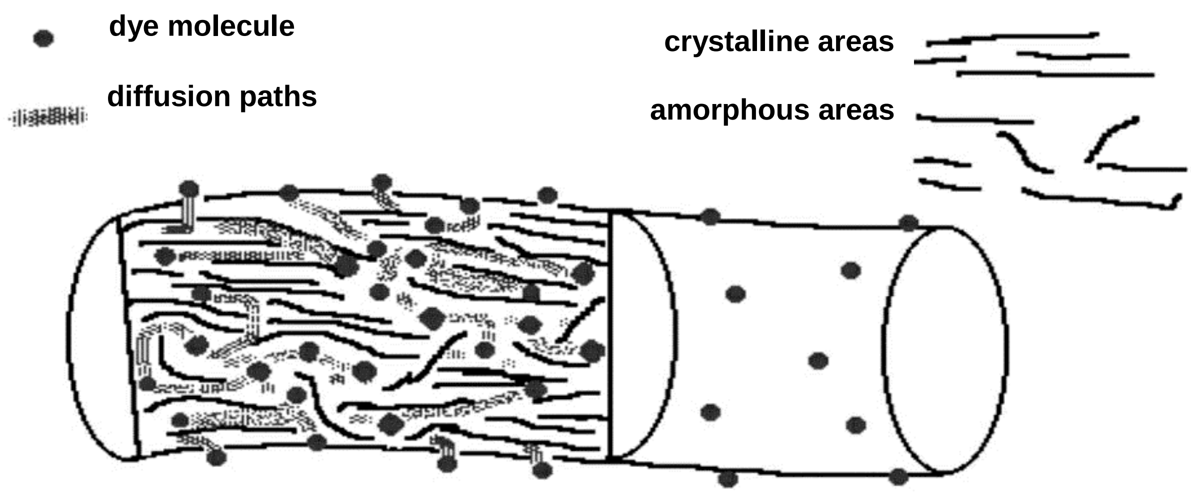



*Picture 37 - Dye concentration in the liquor near the fibre depending on the hydrokinetic condition*

**Third stage** (Diffusion)

During this stage the dye, adsorbed in molecular form by the surface, by breaking and restoring the bonds many times tends 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:

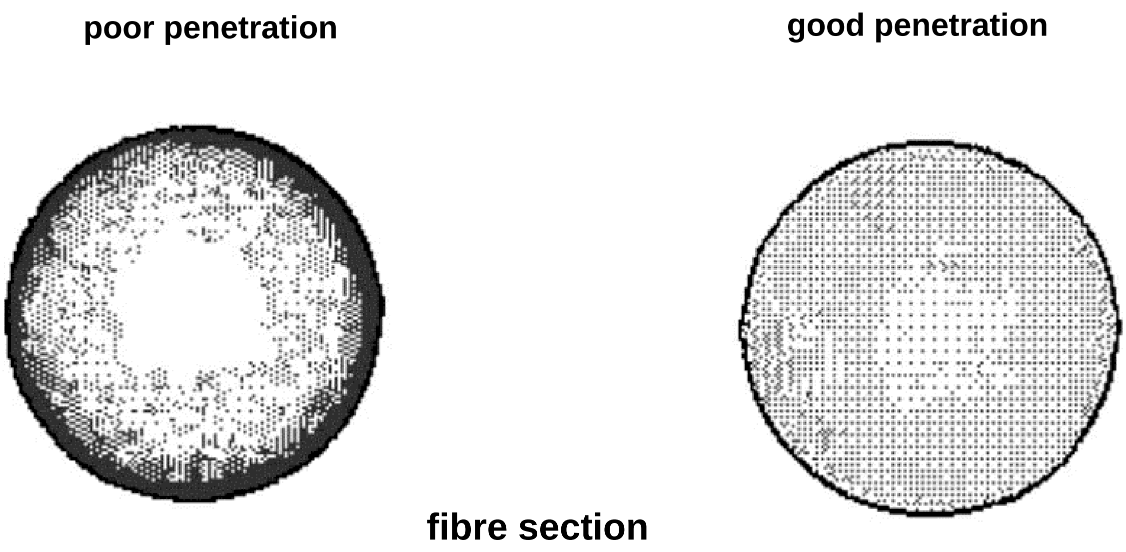
- Crystallinity of the fibre: the dyes penetrate the fibres through amorphous areas and therefore the higher the crystallinity, the lower the diffusion speed.
- Molecular size of the dye: the bigger the dimensions of the dye molecules, the more difficult the diffusion through amorphous areas.
- Strength or 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 the fibre. This leads to a swelling of the fibre and makes the diffusion quicker but simultaneously reduces the affinity and therefore the exhaust (Picture 38).




*Picture 38 – 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 - Picture 37).
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 adequate to allow a good penetration of the dyes, since this is a prerequisite for developing the maximum fastness (Picture 39).




*Picture 39 - 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 the colour consistency.
Low affinity, poor crystallinity of the fibre, small molecular size of the dye will favour this stage, though negatively affecting dyeing solidity 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 effect 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 dyeing agents tend to precipitate at excessively low pHs, and also in the presence of hard water or large-size cations; cationic dyeing agents could precipitate in neutral or basic environment, and in the presence of large-size anions.

## Preparation 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 consistency of the dye distribution (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:

**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 skeins, packages or beams)
- Machines for dyeing woven-knitted fabrics or rope knits (the width is not spread)
- Machines per dyeing open-width fabrics (the fabric is opened and flattened)
- Machines for dyeing made-up garments.

**Classification according to the processing method:**

The processing method to be applied depends on the quantity of materials to be processed and on the type of finishing process.

- Discontinuous (batch) systems.
- Semicontinuous systems.
- Continuous systems.

**Classification according to the operating principle:**

The system to be used depends on the elements that make up the material (fibre and eventual weave), as well as on the type of treatment to be carried out.

- Circulating liquor systems.
- Systems moving the material.
- Systems moving both the dyebath and the material.

**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.

- Systems that can work under pressure at high temperatures (HT autoclaves)
- Open systems, or, systems that run at a max. temperature of 100°C.

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

**Machines to process staple, sliver and yarn** (General remarks)

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 (packages, cheeses, etc). With the use of modular and interchangeable carriers it is possible to carry out loading and dyeing processes using packages 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 best satisfy the growing demand for system optimisation.

**Open-width dyeing machines** (General remarks)

These systems are used for dyeing open-width and well-flattened fabrics.
These systems can be used also for carrying out pre-dying treatments (for example upgrading, bleaching, mercerising), dyeing treatments and wetting operations for both types of treatment.
Among the systems used for open-width treatments it is worth pointing out mercerising machines, jiggers, pad dyeing machines, beam dyeing machines, continuous washing systems, stenters.

**Rope dyeing machines** (General remarks)

These machines process the fabric fed and driven lengthwise to form a rope. The hydrodynamic effect is obtained by means of 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 made up of extremely different fibres, woven or knitted fabrics, 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 benefit obtained with these machines is the extremely soft and fluffy hand, particularly suitable for fabrics to be used for garments.
Possible problems are connected to the formation of permanent wrinkles on the fabric, or to uneven dyeing shades, always connected to the problem of the rope wrinkles; for fabrics made up with very delicate or short staple fibres, mechanical stresses can cause losing or extraction of the hair on the surface.

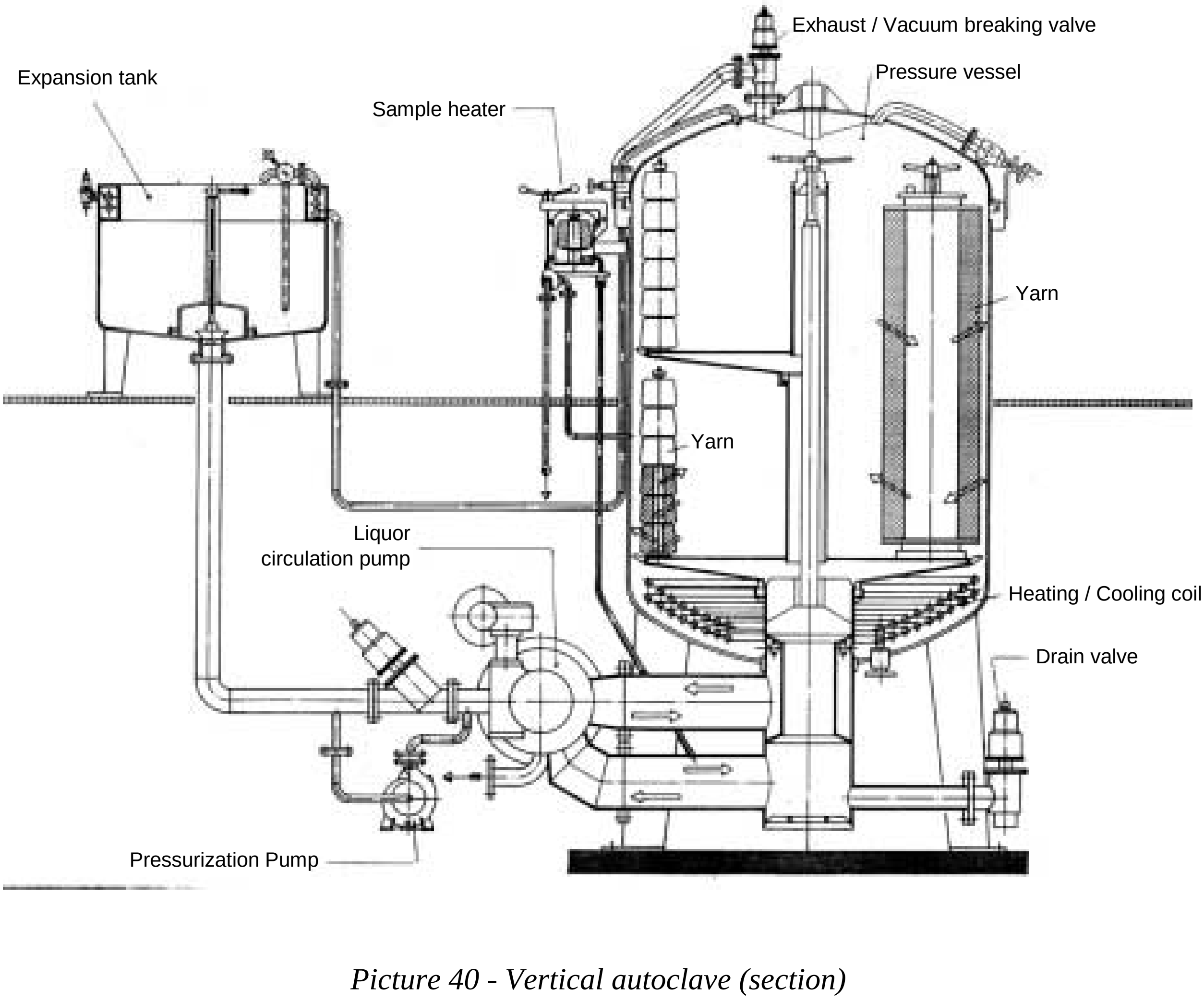
**Piece dyeing machines** (General remarks)

These are discontinuous processing systems; 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 system removes the liquor in excess from the fabric by centrifugation before unloading.
These machines are equipped with automated systems to optimise the process.

# Autoclaves

These machines are used for dyeing staple and yarns in different forms (package, cheese, beam etc.).
These systems are essentially made up 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, package carriers, cheese carriers, fabric beams, etc.)
- Circulating liquor pump (with flow reversal system)
- Expansion vat to balance 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 whatever the operating temperature)
- Sample heater
- Control board for partially or completely automated dyeing cycle.




*Picture 40 - Vertical autoclave (section)*

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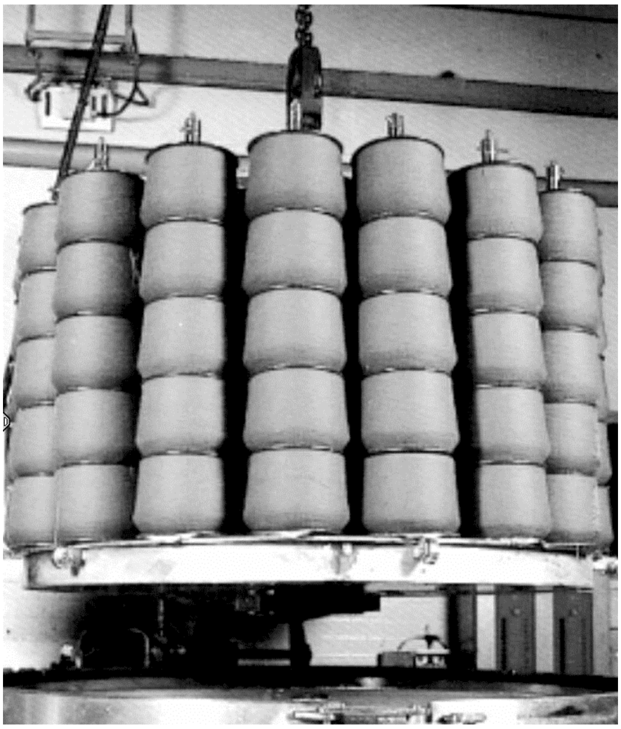
** Some passages and pictures of this chapter have been taken from the book "Nobilitazione dei Tessili" by Franco Corbani, published by Centro Tessile e Abbigliamento (Textile and Clothing Centre) in 1994.*

All manufacturers can now supply these machines equipped with microprocessor or PLC programming system for controlling and setting all the operating functions (filling / exhaust / heating / cooling / stage / dosing etc.) of the whole production cycle and, in specific cases, for adjusting the pump flow according to preset parameters.
Some autoclaves are also equipped with Air Pad pressurizing system, which offers the opportunity to reduce the liquor ratio and the energy consumption; when the machine is running only the carrier, the heat exchanger and the circulation pump are completely immersed in the liquor, while the free space is filled with compressed air.

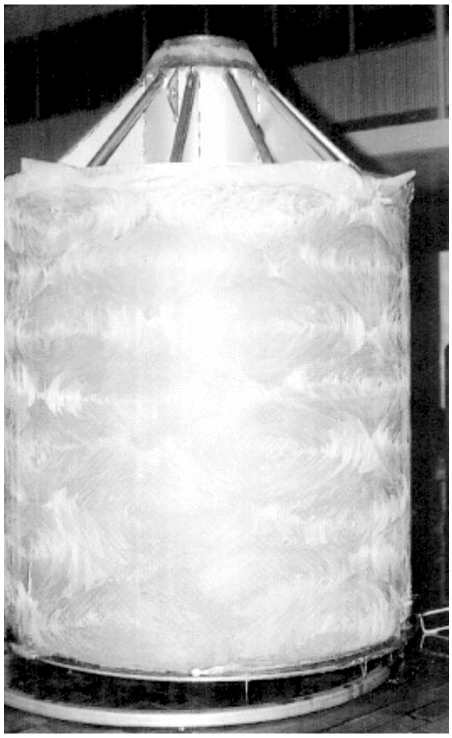
Systems equipped with volume or air reducers are actually used to satisfy the increasing demand for machines where batches with different weights can be loaded and treated (thus keeping a steady nominal liquor ratio).
Thanks to these systems, the machine can process from “1” to an “infinite” quantity of packages for each shaft entailing considerable energy saving, cutting plant and production costs, as well as a considerable reduction of delivery times.
In the past, the reduction of the loading capacity thanks to the air cushion could only be ensured with vertical autoclaves; now it can also be obtained with horizontal units.

*Picture 41 – Horizontal autoclave for packages*

An autoclave model used only for packages includes many small horizontal heaters (basically coils) instead of a single heated vat; each small heater can be loaded with a single package carrier shaft. This autoclave allows working with an extremely low liquor ratio.
The material to be dyed must always be accurately arranged to avoid possible disproportion in the liquor forced under pressure through it, in both directions alternately, from the core to the outer surface and vice versa, according to programmable times (for example from 2 to 4 cycles per minute).

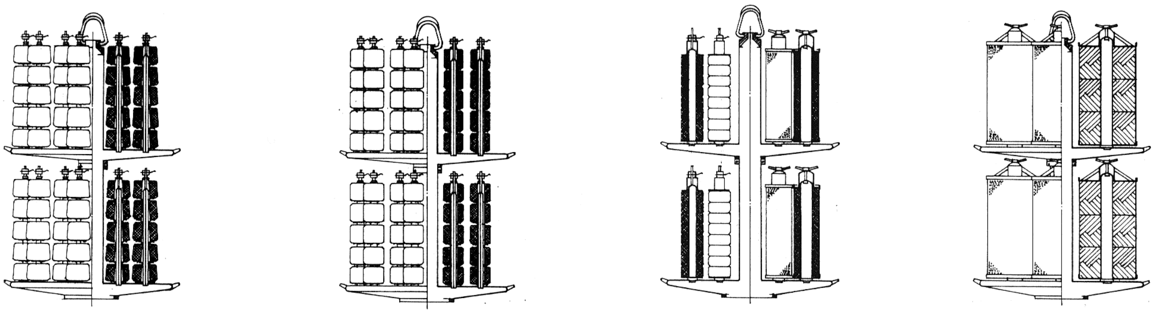


*Picture 42 - Package carrier*



*Picture 43 - Staple 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 operating pressure of 5-6 bar, and are statically pressurized by means of a pump or of a compressed air cushion; 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 overlapping levels, which can be separated for easier loading and unloading. In fact these machines, besides packages, cheeses, tops, etc, which can be loaded in single-level machines or in machines equipped with horizontal heating vat, can be loaded with fabric beams; they also allows cutting the loading capacity in two (see drawings of the different carriers) thus increasing the operating flexibility.



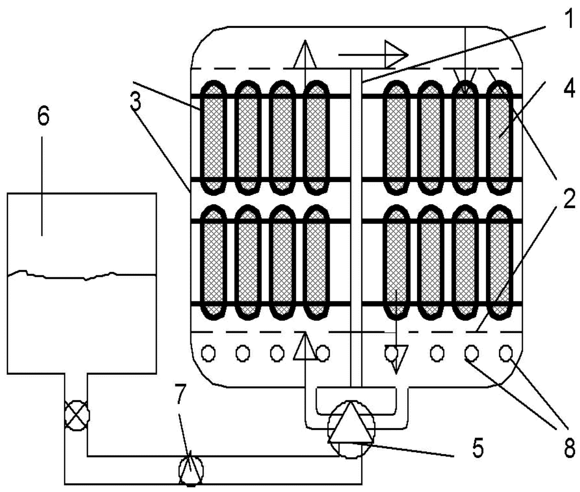
Cones | Cylindrical packages | Cheeses | Tops

*Picture 60 – Different types of two-level overlapping carriers*

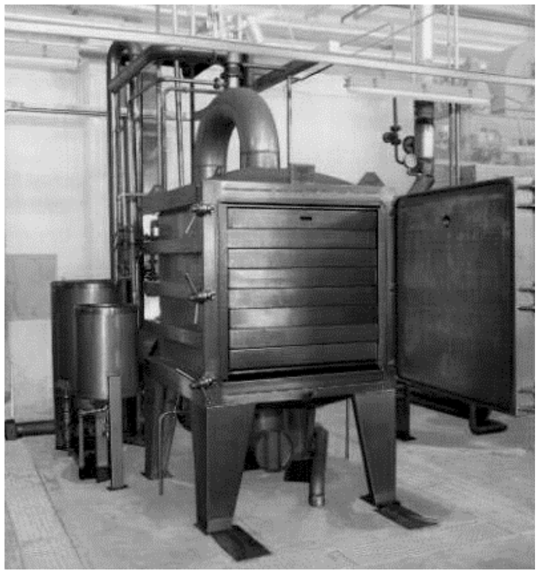
With reference to the drawings above, we only need to add some detailed information about package yarn dyeing. This dyeing system is more popular than staple and hank dyeing (cheeses are no longer used) since it is more cost efficient and environment friendly.
The diameter, and therefore the weight, 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 the dyestuffs used. Packages can be prepared by winding the yarn on perforated taper 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 to 3.5-4 kilograms for large polyester packages.
The dyeing sector has recently undergone a very incisive improvement in automation and robot control. Particularly, 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).

## Hanks

Hanks are used for the dyeing of skeins; a hank is made up of a parallelepiped-shape vat divided into compartments by perpendicular partitions. The skeins 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/cm2. If the pressurisation is obtained by means of an air cushion, 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.



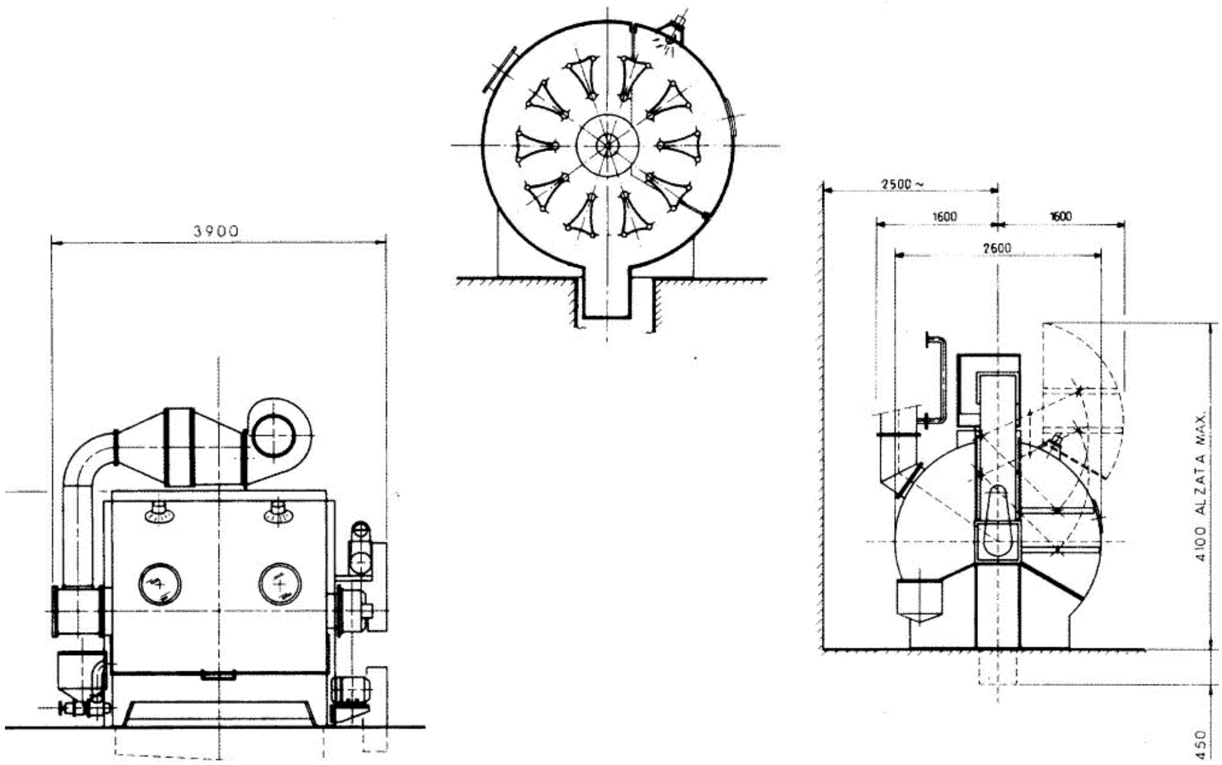

*1 central wall; 2 perforated separators;*
*3 perforated supports; 4 skeins; 5 circulation pump; 6 expansion vat;*
*7 auxiliary pump; 8 serpentines.*



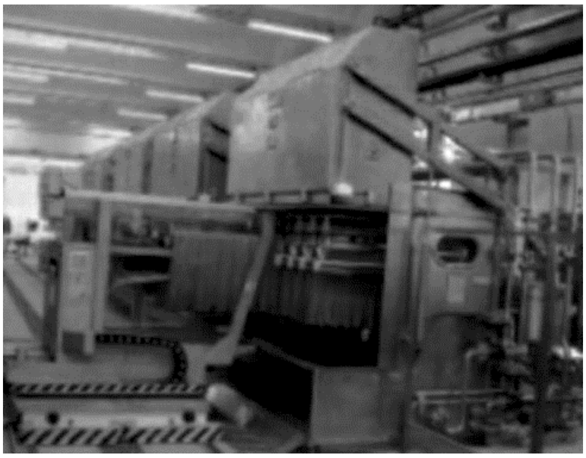
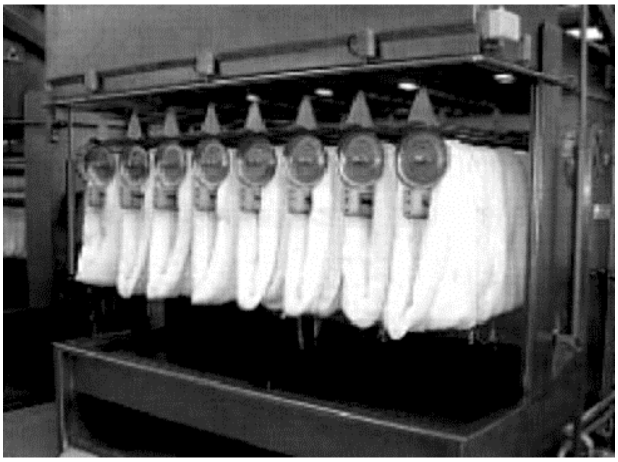
*Picture 43 - A skein dyeing system (hank).*

# Arm Dyeing Machines

This is the most suitable machine for dyeing delicate yarns (silk, Bemberg, etc.) since it prevents the material being too tightly packed; in fact other skein dyeing systems frequently produce an excessive packing of the dyed material. The machine is equipped with horizontal arms perforated in the upper part; skeins are stacked and suspended on this rack. The liquor, forced through the arm holes, penetrates the skeins and is then collected in an underlying vat. Standard machines are equipped with a rod which moves the skeins at preset times, changing the bearing point to obtain a more uniform dyeing. During the skein 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 steady temperatures since the liquor is contained in a separate tank.
The operating costs of this machine are generally very high because it require 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 skeins; the skein rotation is determined by the perforated arms, and not by the rotation of the skein-lifting device when the arm is stopped; it is therefore possible to eliminate the sliding contact with the skeins and preserve them perfectly.
There are also package dyeing machines with triangle-shape 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 skeins.




*Picture 44 – A skein dyeing machine. This machine is equipped with triangle-shape arms, arranged radially on a variable speed rotor*

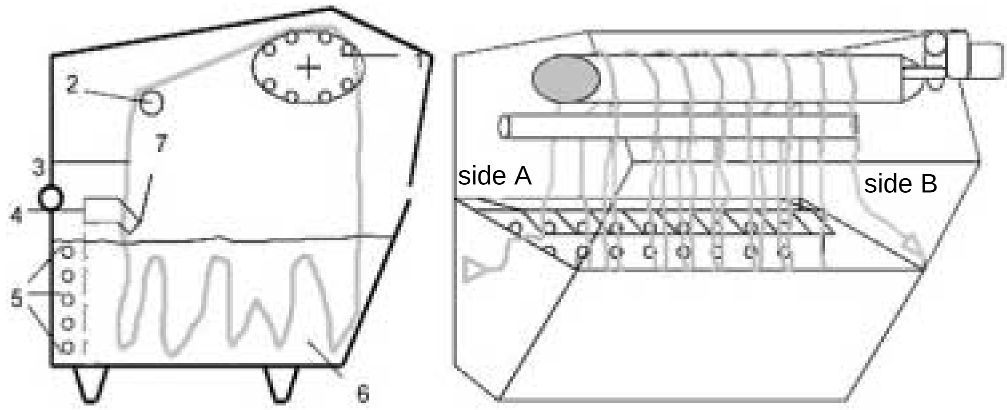
 

*Picture 45 – Modular skein dyeing machine with pullout arms.*
*Pullout arms also allow the loading and unloading of skeins far from the dyeing machine, without manually intervening in the intermediate dyeing, squeezing and drying operations. It can be used for silk, cotton, viscose and Cashmere yarns.*

## Winch Dyeing Machines

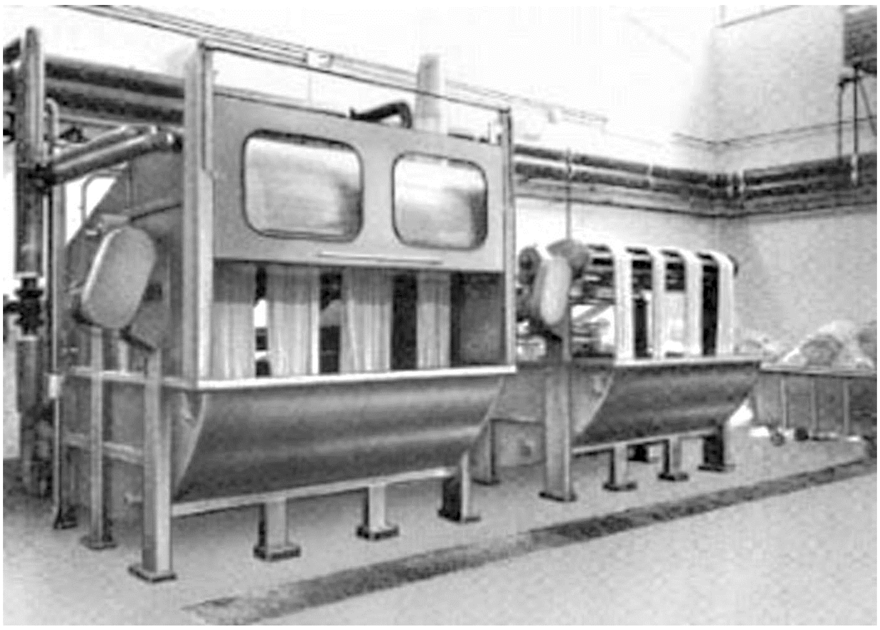
This is a rather old dyeing machine for fabrics in rope form with stationary liquor and moving material. The machine operates at a maximum temperature of 95-98°C. The liquor ratio is generally quite high (1:20-1:40).
The system includes a vat with a front slant side acting as chute for the folded rope, while the rear side is entirely vertical. A perforated separating compartment, 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 heating.
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.
The rope to be dyed then 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 the tail with the head 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 system requires high energy consumption, 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 freedom of the rope folds could negatively affect the dyeing results.
This is one of the oldest systems used for finishing treatments, but it 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, Picture 47), 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

*Picture 46 and 47 - A winch dyeing machine*

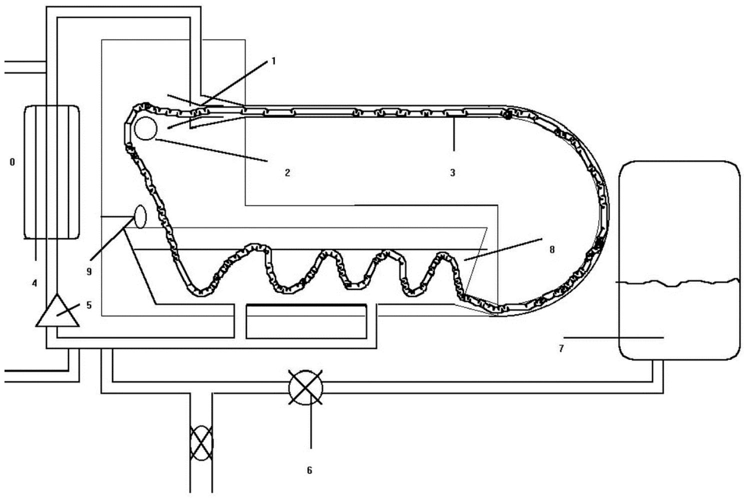


*Picture 48 - Winch dyeing machine*

# Jet Dyeing Machines

These machines, where both liquor and material move, are used for rope dyeing and preparation; 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 in different categories: for example, there are machines only partially filled with liquor, suitable for treating PL or PA fabrics and for synthetic filament fabrics and machines completely filled with liquor, used for more delicate fabrics (the fabric is carried over more delicately and is always immersed in the liquor). Now the trend goes towards the production of machines with a more delicate fabric drive, which adds to the hydraulic drive of the jet system a mechanic drive carried out by means of a large-size reel; this makes this multi-purpose system more flexible and therefore suitable for treating a steady wider range of fabrics.

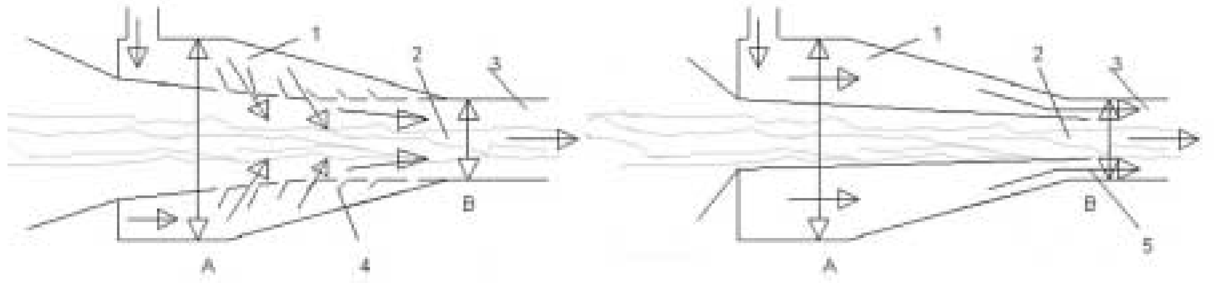
Partially filled jet system (Picture 49): The external part of the machine is made up of an autoclave, generally horizontal and cylinder-shaped, with a turret on one side, provided with an access door and glass window; the jet nozzle from which a tube starts, is usually assembled inside the turret. The 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 reaching the lifting compartment (the turret). Inside the turret the rope is lifted up and, running on an idle or power-driven cylinder (reel), it is immersed in 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.




*Picture 49 – Drawing of a partially filled jet system*

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

The external part of the jet transport system (applying the Venturi principle) (Picture 50), is made up by an external funnel (nozzle) 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 Picture 1A), until it reaches very high speeds (500-1400 m/min., depending on the flow and on the diameter). The liquor flow is powerfully directed toward the fabric inside the transport tube. The friction generated by the rapid liquor flow between the dye solution and the rope makes the fabric float through the tube; at the same time, the powerful motion of the flow facilitates the removal of creases on the rope.




*Picture 50 – Ejector*

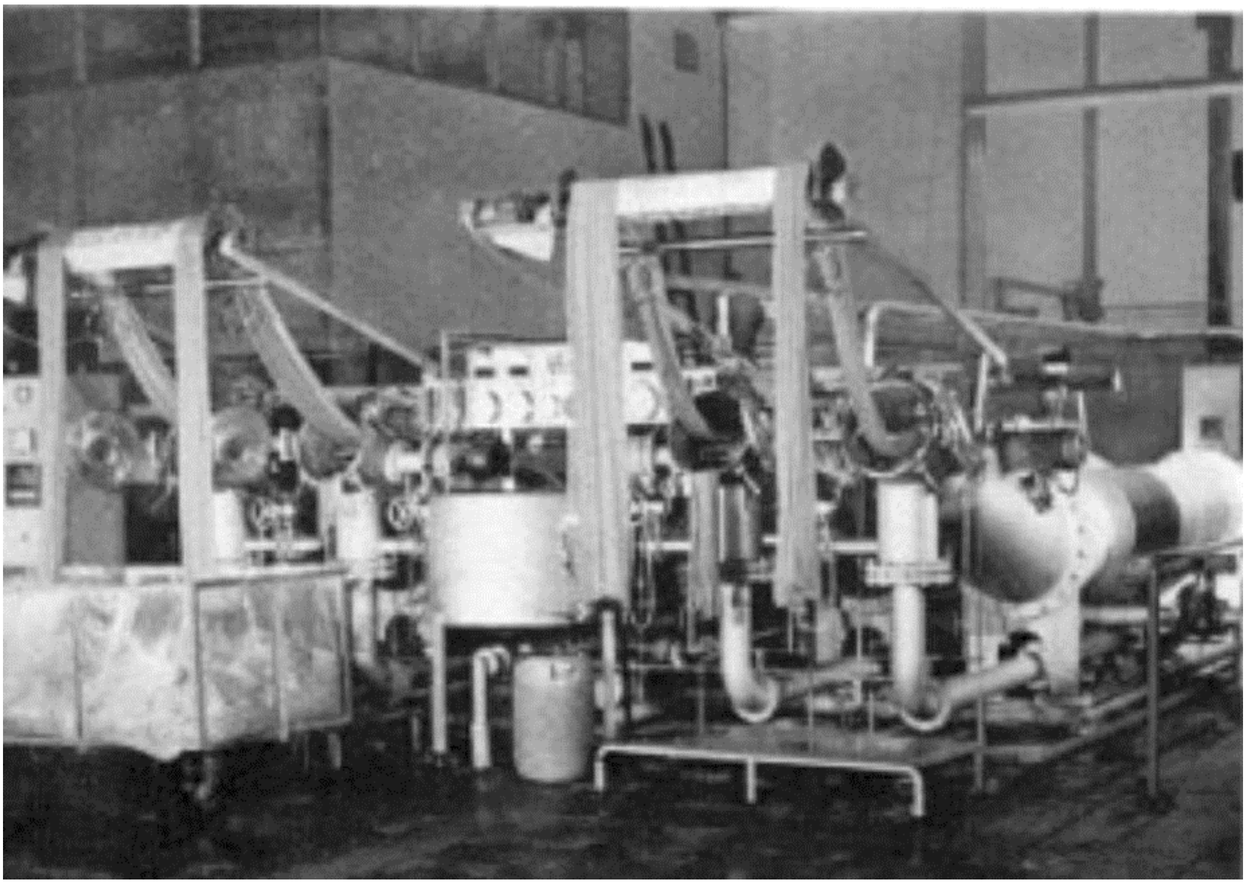
*1 – Jet system* *4 – Fins*
*2 – Fabric* *5 – Neck*
*3 - Transport tube*

The circulation speed of the fabric can be adjusted: 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 the formation of hairiness on the surface. The great difference of speed 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.



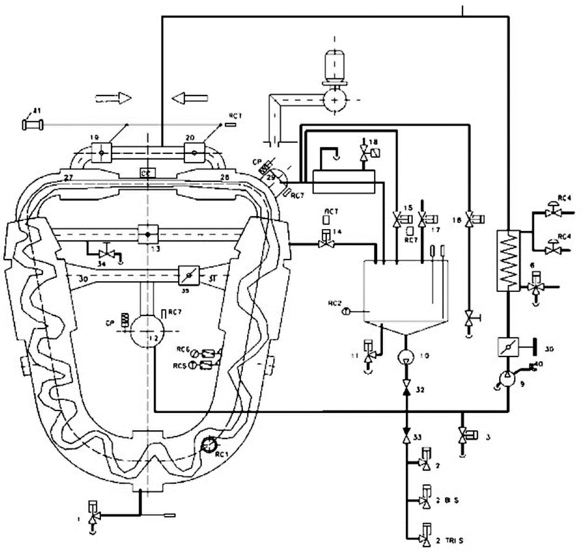
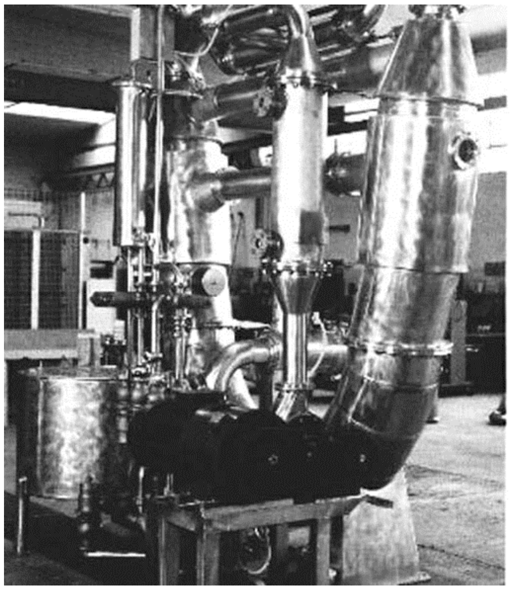
*Picture 51 – A jet dyeing machine*

*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 external-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 maximum fabric circulation speeds 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 subjected to peeling or the formation of hairiness on the surface.

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 process 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 wool or blend fabrics, with short process times and low costs.

Picture 52 shows a completely filled jet system, 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 the dye consistency and preventing ropes from entangling.

*Picture 52 - Drawing and picture of a completely filled jet machine*

## Overflow Dyeing Machines

This dyeing machine is used for pre-treatment and dyeing of rope fabrics, with both liquor and materials moving (Picture 53); the architecture and the design of the system and the liquor ratios are similar to the jet machine ones.
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 and to the limited speed on one side and to high liquor flow and to the large-size transport tube on the other one. This machine is therefore suitable for delicate fabrics, too – 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.).

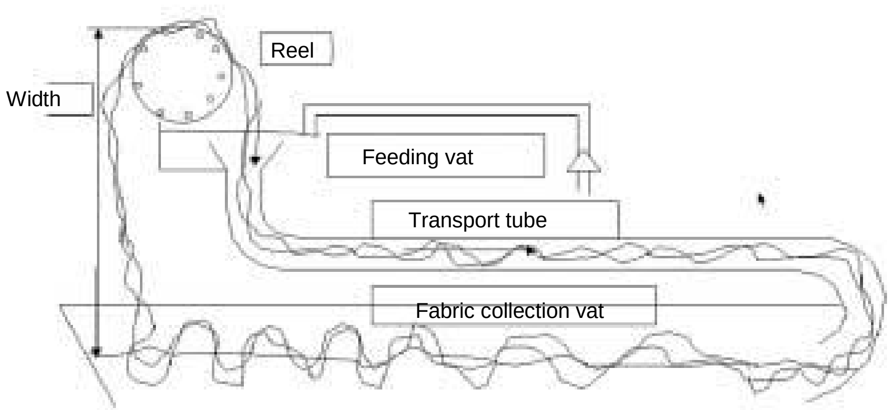
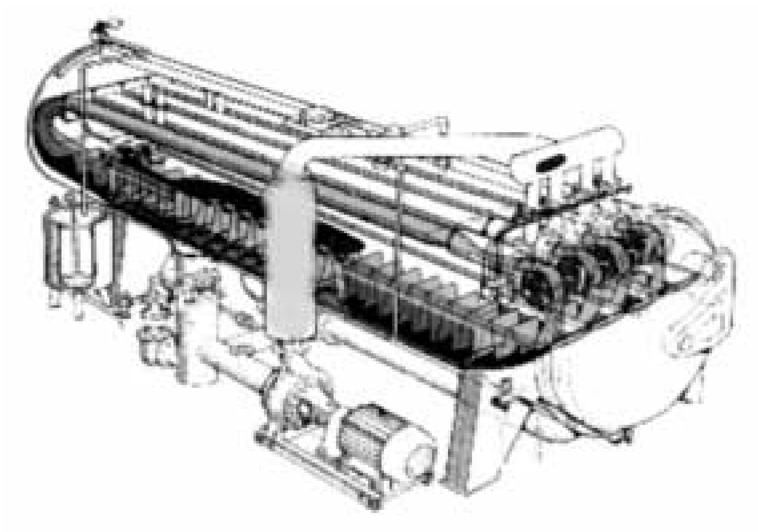


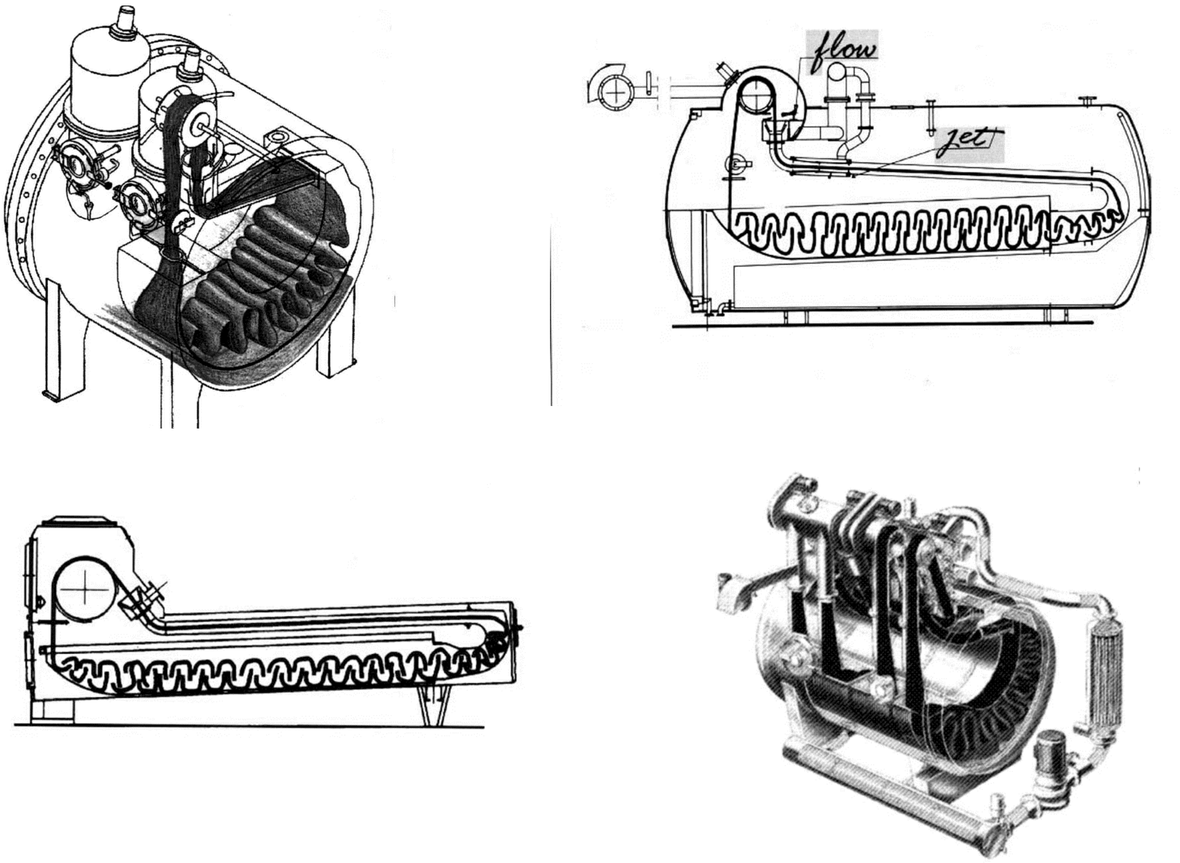

*Fig 53 - An overflow dyeing machine*



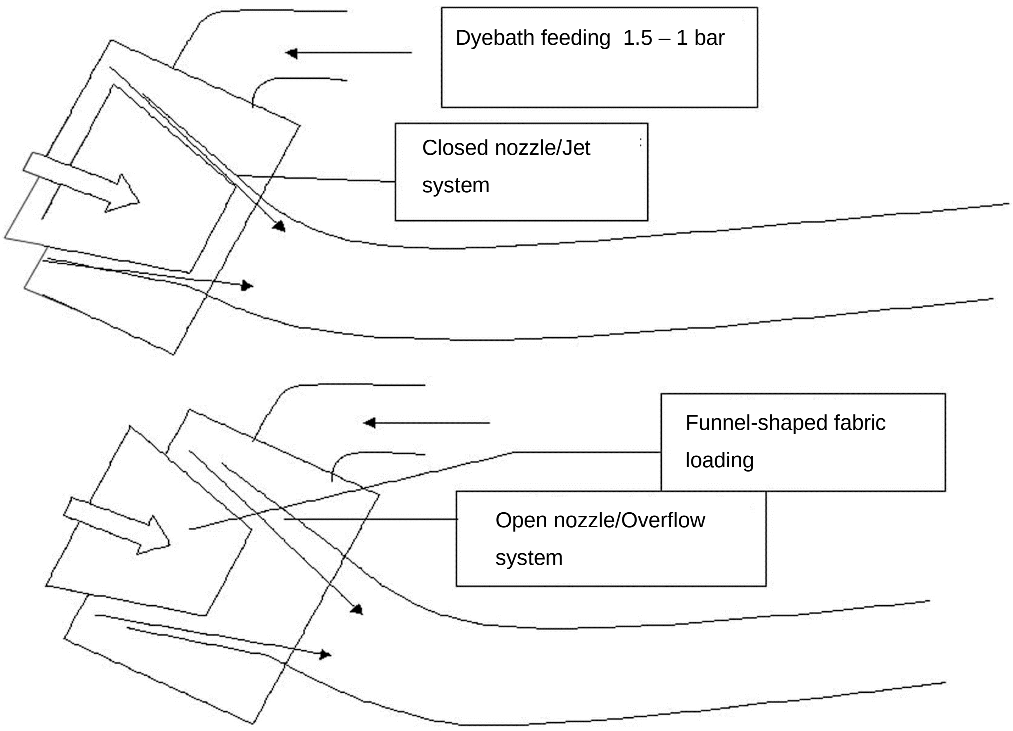
*Picture 54 – Drawing of a four-rope overflow system*

The builders of overflow systems supply machines working at high temperatures (from 130 to 140°C), particularly suitable for processing synthetic fibres and synthetic fibre blends, and 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 with temperatures near 100°C.
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 ever-changing customer needs.
The most interesting solutions are:

- Flow-jet systems: to transport the fabric these machines apply a system based on the Venturi principle also known as drop principle and a motorised reel (Picture 55 B and D).
- Jet system with adjustable nozzle to allow a non-stop change of the transport effect (when the nozzle is closed the jet effect is very powerful while when the nozzle is open the machine runs in the overflow technique) (Picture 55 A and C – Variable nozzle in Picture 56).
- Vertical machines where the fabric is lifted at 1-1.5 m. from the liquor level, with a certain stress on the fabrics (these machines ensure high transport speeds, suitable above all for continuous artificial and synthetic fibres) (Picture 55 A, B and D).
- Horizontal machines, where the fabric is slightly lifted from the liquor level, with subsequent low tensile stresses and transport speeds (suitable for delicate fabrics) (Picture 55 C).
- Machines with long (Picture 55 A and C) or short transport tubes (Picture 55 A and D) or with differently shaped tubes to better suit the various types of fabric (Picture 55 A, B and C).




*Picture 55 – Various types of jet and overflow systems*



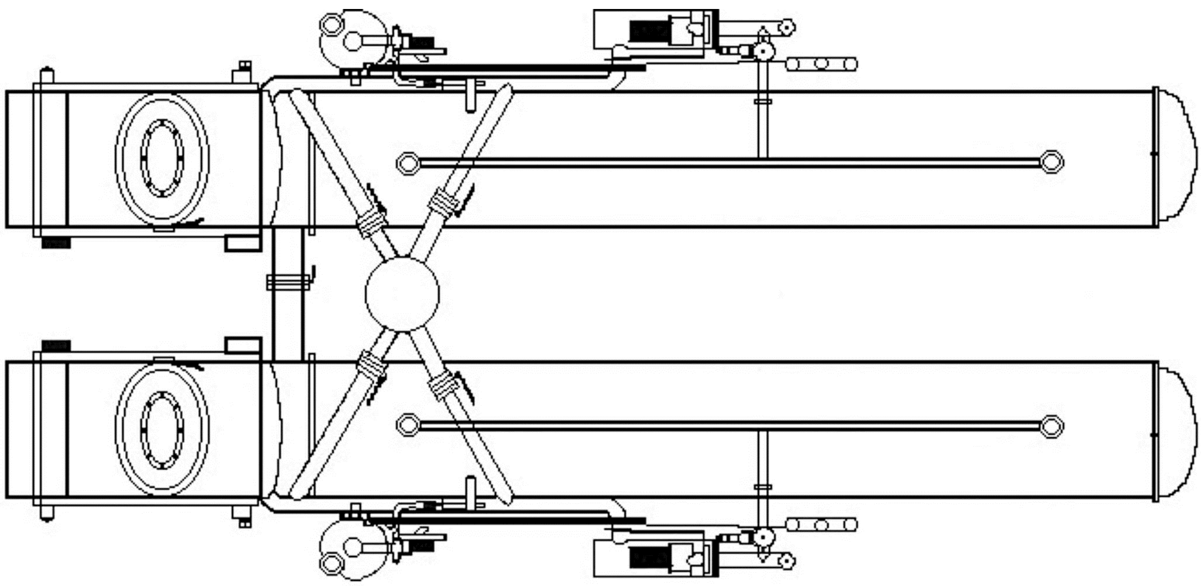

*Picture 56 - Jet/flow variable-position nozzle*

- Machines with slant or Teflon-coated collecting vats to improve the sliding of the folded fabric and reduce the problems of fibrillation, abrasion and/or projecting yarns (Picture 55 C).
- Transport tubes slightly leaning upward to reduce the friction of the rope with metal surfaces (the fabric is drawn always immersed in the liquor) (Picture 55 C).
- Air blowing in the nozzle or in the flow to improve 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 (Picture 55 C).
- Hydraulic system to improve a uniform folding/plaiting of the fabric without entangling (Picture 55 D).
- Possibility to drain the liquor at temperatures exceeding 100° C (if possible, in order to reduce the process times) (Picture 55 D).

To optimise either output capacity and production flexibility, builders have studied different solutions. It is worth remembering 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

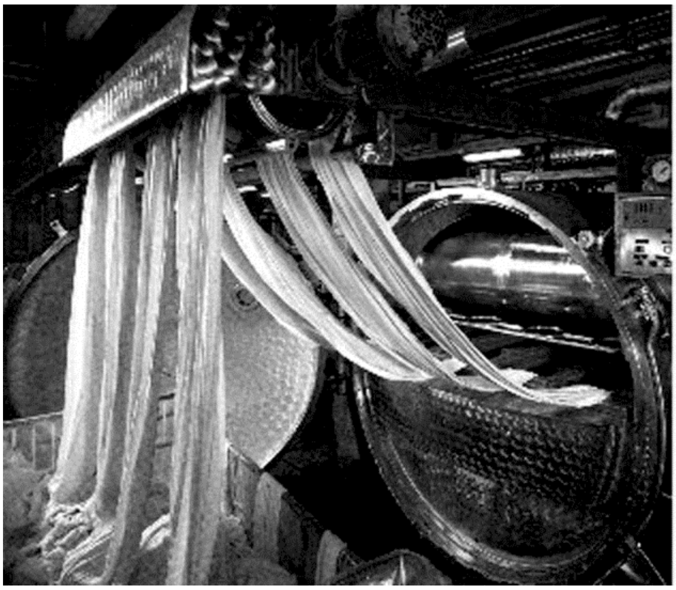
Briefly, to process lots of different sizes (from 50-60 kgs to 800-1200 kgs) the manufacturers can build machines that can load many ropes (with separated collection vats - Picture 58, Overflow - Picture 54), or machines with only one rope and variable path (Picture 55 D).

To increase process flexibility, the machines (with 1, 2, 3 or more ropes) can be twin-type; two identical machines that 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 the same operating conditions, thus doubling the loading capacity (Picture 57).



*Picture 57 – Twin flow systems*

Both jet and overflow systems are equipped with a motorised reel for loading/and/or unloading the fabric (Picture 58).



*Picture 58 – Picture of a 3-rope flow system*

## Air-flow (Air Jet) Dyeing Machines

These are the most modern rope dyeing machines currently available on the market. The operating principle is similar to the jet dyeing system, but the fabric, guided by a motorised 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 one that the fibre can actually absorb. When the fabric folds in the perforated collection vat, it releases the excess liquor, which is recirculated by the special pump.

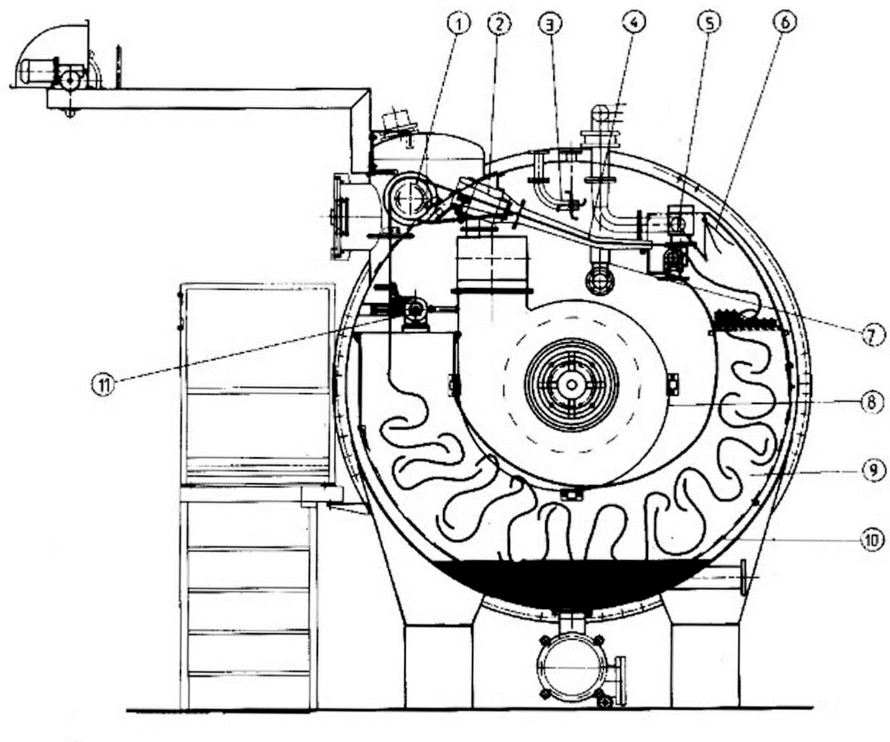
The fabric transport speed can be also very high (between 250 and 1000 m/min) while the liquor ratio could be, in theory, 1:1 to 1:2; in standard processing conditions the liquor ratio is 1:3-1:8. This machine usually allows high temperature process.

The high speed of the fabric fed, together with the reduced liquor ratio, guarantee optimum dyeing results in very short times; it also reduces water consumption and the quantities of auxiliaries and dyes necessary for an optimum dyeing process, thus leading to considerable cost reduction (also with regard to wastewater 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 helpful.

These machines have been designed for dyeing fabrics made of synthetic fibres, blends of man-made and elastic fibres, and microfibre fabrics; in reality these machines have proved to be extremely suitable for dyeing man-made filament. 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 for the extremely reduced quantity of liquor, thus leading to permanent wrinkles.

This problem becomes clear above all for fabrics made of synthetic fibres, particularly when they have not been efficiently heatset, and sometimes it is amplified by the water blade beating the fabric at the exit of the nozzle.
These systems 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 rope) machines. In detail, the machine shown in Picture 59 is equipped with:

1- Reel for feeding the fabric at variable speed ranging from 250 to 700 m/min. (1,000 with a pressurised machine).
2- Air blower feeding the ejector by taking the air from inside.
3- Machine's internal washing system.
4- Transport tunnel facilitating the progressive rope opening.
5- Spraying of the liquor atomised at the tube exit side (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.



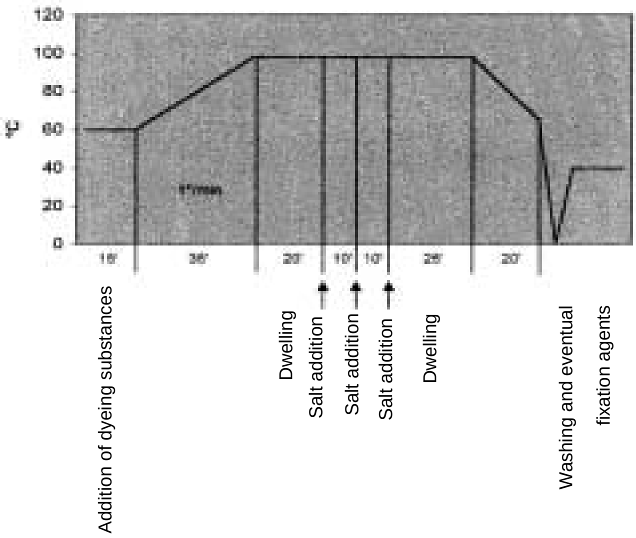

*Picture 59 - Air jet dyeing machine*

The application of electronics and IT systems has 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 sewn fabric, with consequent calculation of the average rope circulation speed and stoppage of the sewn fabric near the door for quick sampling strategies.
- Electronically controlled pumps, reels and variable-speed air blowers.
- Devices for measuring the transport tension of the fabric, and the 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.) feeding of additions from the automatic colour kitchen (or from the addition vat), and light and/or acoustic alarms for the operator.
- Security systems for door opening in pressurised machines.
- Possibility of recovering heat by preheating fresh water with the exhausted liquor.

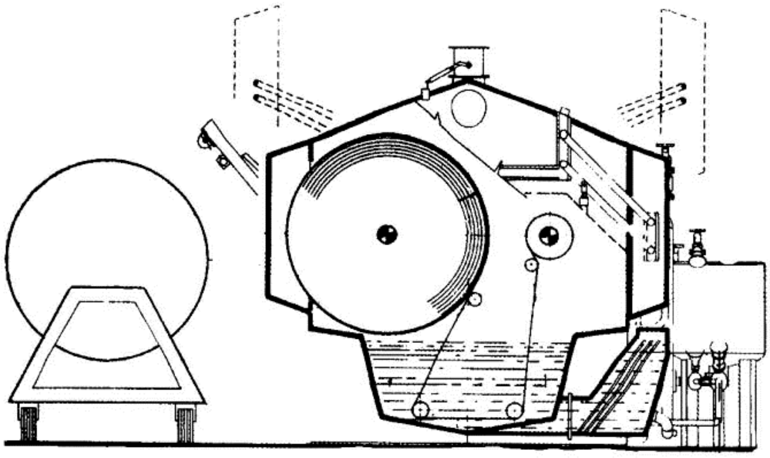
Operations to be carried out during the process cycle:
- The process cycle is programmed or a previously stored one is retrieved
- The water is poured in (cold/preheated/softened /hard water) and the level is controlled.
- The fabric is fed into the machine: unwound from a beam, or folded on a carrier, by means of jet or flow system.
- The head of the fabric is recovered from the collection vat and the piece head is sewn with its tail.
- A magnet is introduced in the sewn section (for machines working with high temperatures).
- The cycle is started.
- Possible addition of chemicals/dyes (automatically from colour kitchen, semiautomatically or manually from addition vats).
- The variable process conditions are monitored by means of control board; visual control is carried out from the glass 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 re-dyeing cycle must be started).
- The fabric is eventually washed and/or rinsed.
- Once the cycle has been terminated, the sewing is removed and the fabric is unloaded by means of the motorised reel.
- Washing machine.

*Picture 60 - Example of a dyeing diagram, as displayed on the monitor of a dyeing machine*



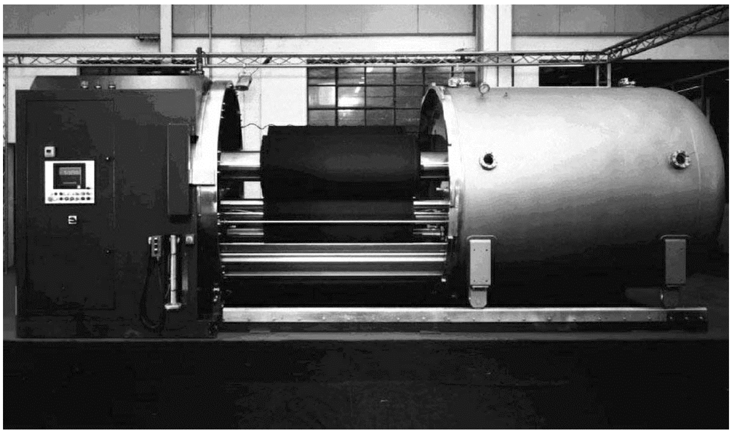
# Jiggers

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



*Picture 61 - A jigger*

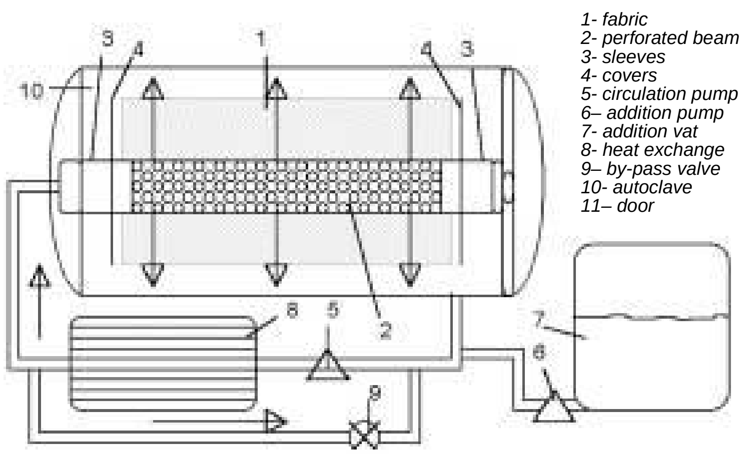
The fabric pieces are sewn together tail-to-head, forming a sort of “ribbon”. At the head and at the tail of the ribbon two cloths are added (4–5 m long) to allow the regular dyeing of the whole pieces, also leaving the machine drawn-in once the dyeing process has come to an end. The assembled pieces are taken down from a roll, pass through the liquor (they are kept in the correct position by means of transport cylinders and a tension equaliser, which avoids the formation of wrinkles). The fabric is then wound on a takeup roll until the dyeing process has 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 width of the piece of cloth 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 it can be adjusted between 0 and 60 kg. Since the passage time is very short, dyeing occurs above all on the fabric wound on the 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, many additions may be necessary to avoid the so-called head-tail defects. Lightweight fabrics (viscose, nylon) that are stretched excessively during the takeup step can show “shading” defects. Jiggers work with a quite low liquor ratio (from 1:1 to 1:6).
Together with standard atmospheric systems, builders also offer HT jiggers inside autoclaves working at high pressure.
Jiggers are suitable for dyeing all type of fibres.



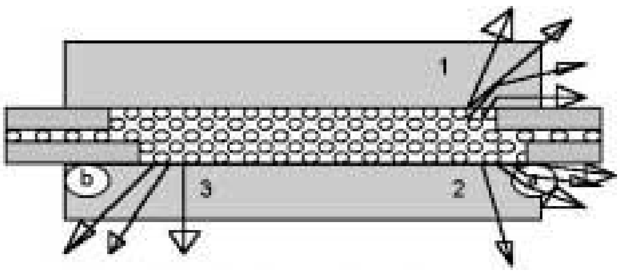
*Picture 62 - A HT jigger*

## Beam Dyeing Machines

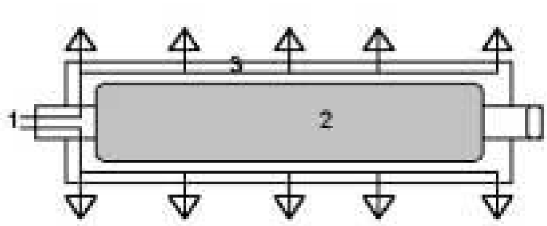
The discovery of polyester - a material requiring very high dyeing temperatures (up to 140°C) - in the 1960s led to the extensive application of beam dyeing machines; they essentially included a dyeing autoclave with circulating liquor, with the open-width fabric lying on a perforated beam provided with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




Nowadays, in order to increase the output capacity and further reduce the liquor ratio, manufacturers have begun 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



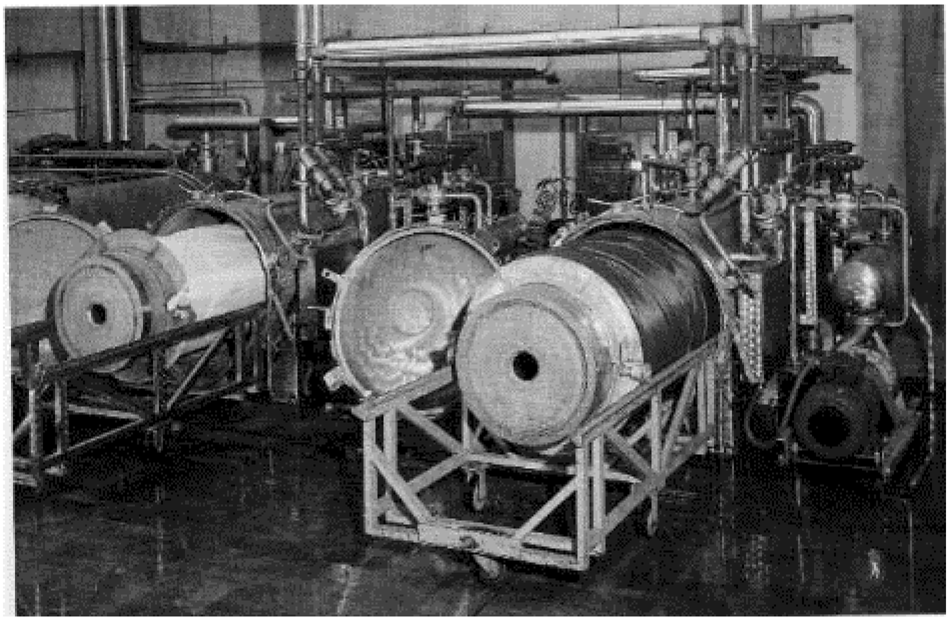
1 - correctly fitted sleeve
correct liquor flow
2 - loose sleeve
excessive liquor flow in (a)
3 - sleeve too tight
poor liquor flow in (b)



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

*Fig 63 - Drawing 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 is shorter than the beam, 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 surface resembles water ripples).
The control of pressure changes (internal/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.
It can be used for both preparation and dyeing operations.



*Picture 64 – Picture of a beam dyeing machine*

## Garment-dyeing Machines

During the last decade, the market has been forcing textile companies to supply sports- and leisurewear in extremely reduced times and in the trendiest colours of the moment. Obviously the standard textile production cycle, contemplating a dyeing process followed by make-up and distribution, which does not run with very short times, leads to a considerable loss of sales.
The piece dyeing process ensures very short times from the customers’ demand to the fulfilment of market needs for cool colours and stylish finishing processes. To meet large or small demands for a given colour as fashion requires, machine manufacturers now offer many garment dyeing and finishing machines. These are generally rotating machines, similar to large-size industrial washing machines; the garments are loaded in special baskets for finishing operations. The machine size and equipment allow the maximum flexibility to meet the most different needs as described in the following.

1- Sizes: from sampling machines with a 50cm 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)

3- Perforated steel sheet metals and beater covers to avoid damage to the basket when treating the fabrics with pumice (stone-wash, ageing).

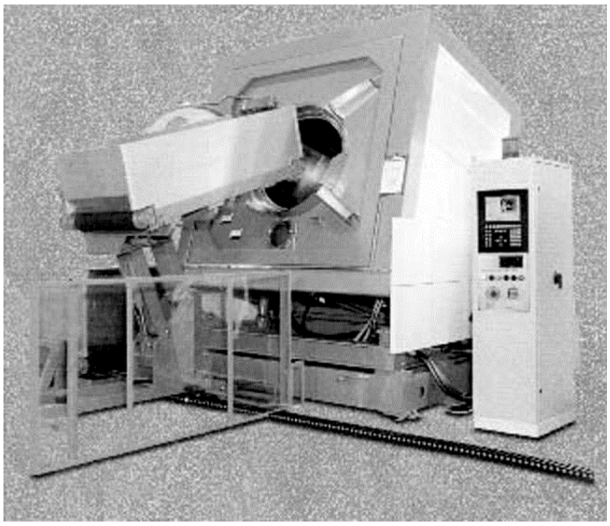
4- Delta or star-shaped separators for treating very delicate garments.

5- Automatic systems for distributing and dissolving dyes and auxiliaries.

6- PLC to program, store and monitor the treatment cycles.

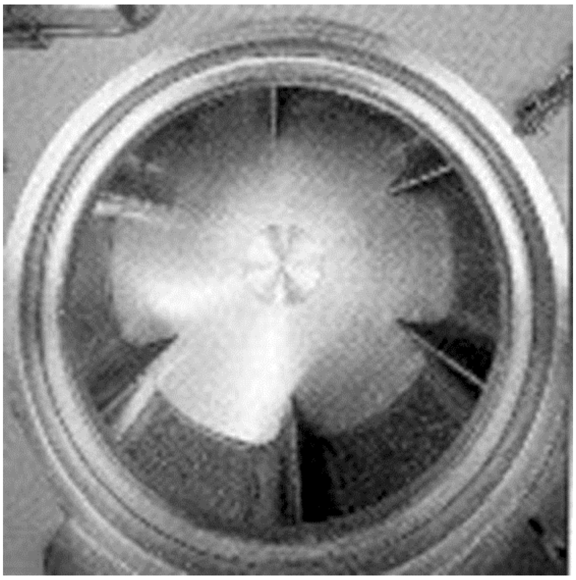
7- Loading and unloading systems provided with robotised shuttle or tilting optional devices.

8- Automatic pumice separation devices during the unloading stage

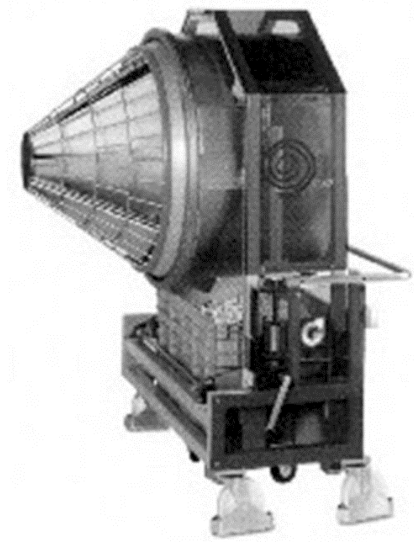


*Picture 65 - Garment dyeing machine equipped with PLC and robotised shuttle loading*

*Picture 66 –Garment dyeing machine equipped with tilting device for unloading.*



Picture 67- Basket detail



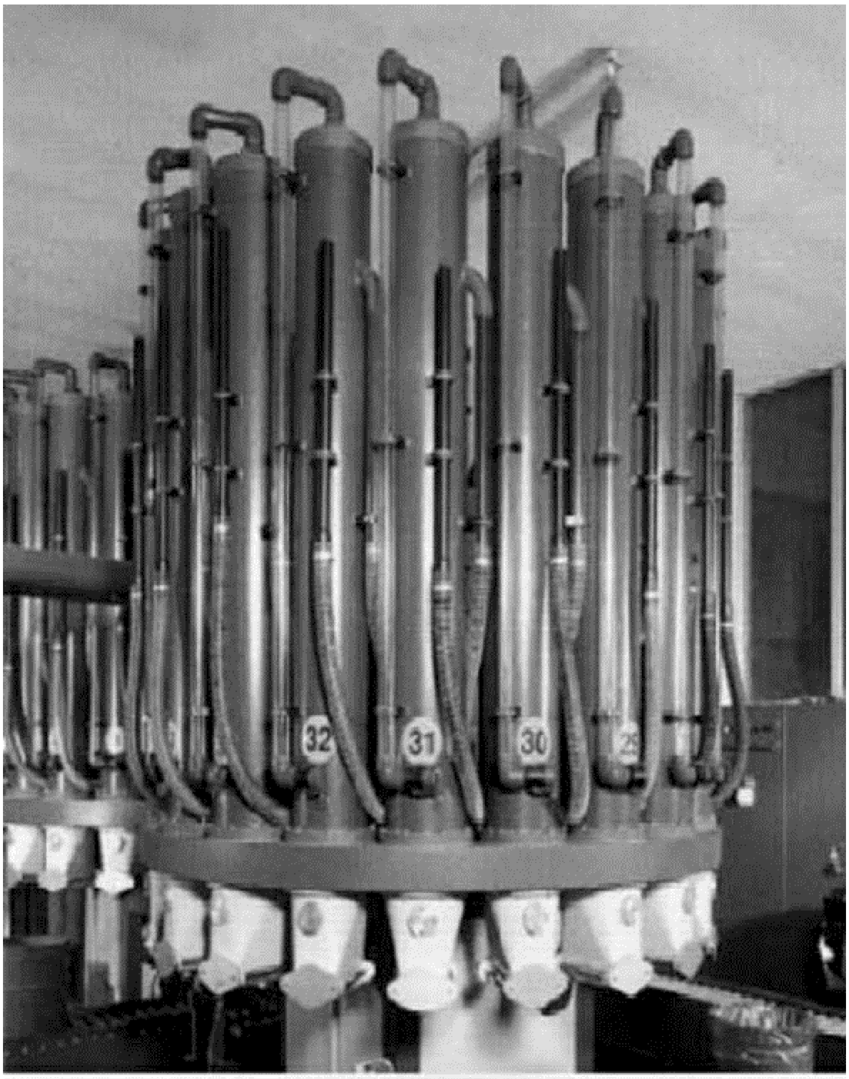
Picture 68 – Pumice separator

It is worth mentioning that most machines can even work at high temperature, thus allowing the dyeing of PE or PE-blend garments.

## Colour Kitchens

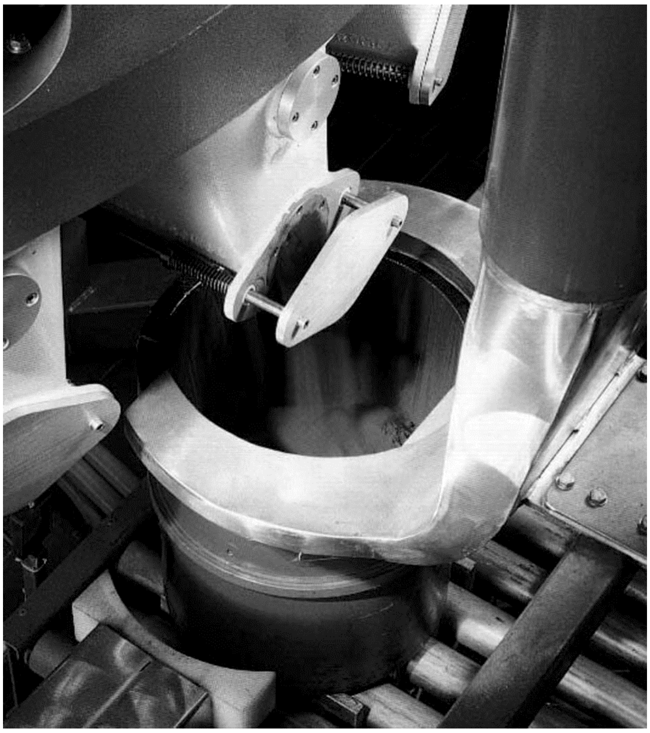
Colour kitchens were once manual systems used for weighing dyestuffs and auxiliaries and dyebath preparation (dyestuff dissolving) carried out by operators who manipulated the colour kitchen directly.
However, this created several problems, both in terms of reproducibility (matching and consistency of the dye, weight, dissolving procedure) and 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 colour 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.
Modern vacuum systems halve the powder dyestuff treatment and dissolving times

(previously, 20 to 25 minutes were necessary to prepare 200-300 litres of dyeing liquor): the previously weighed container (three or four dyestuffs) is sent to the vat for dissolving (the capacity ranges from 30 to 100 litres) by means of a liquid piston rotary vacuum pump, which can deliver from 150 to 350 g/sec of products. The vacuum effect makes the dye dissolve and avoids the formation of undesired adhesion of granular particles. This technique requires extremely reduced water volumes (the remaining quantity is added afterward), the mixing does not produce foams and is carried out at low temperatures and in half the time required by traditional systems. The vacuum effect facilitates the tube and hose cleaning.
By using a 10 kW pump, it is possible to feed a system of four dissolving devices feeding twenty dyeing machines.




*Picture 69 – Dispensers for liquids and automatic feeding of dyestuffs and auxiliaries to the various dyeing machines.*

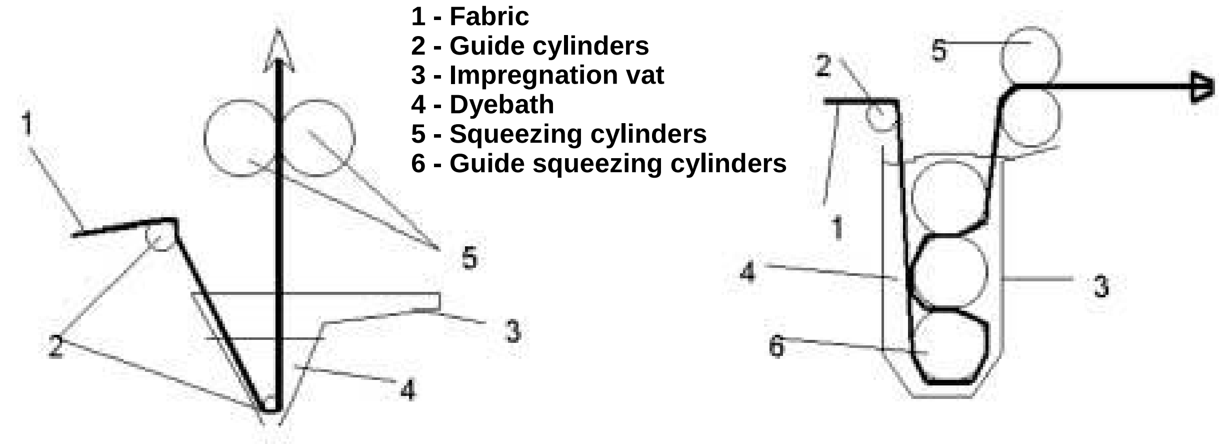
Dyeing machines can be fed directly by automatic systems, which dose and forward chemicals and auxiliaries; these systems are controlled by microprocessors using only one line for transferring operations, with distribution mistakes ranging between 10 and 15 ml.
The pump motors are equipped with variable-speed drives; the draining of fluids is carried out by means of ball valves and materials are generally stored in small suspended containers.



*Picture 70 – Detail of an automatic dispenser*

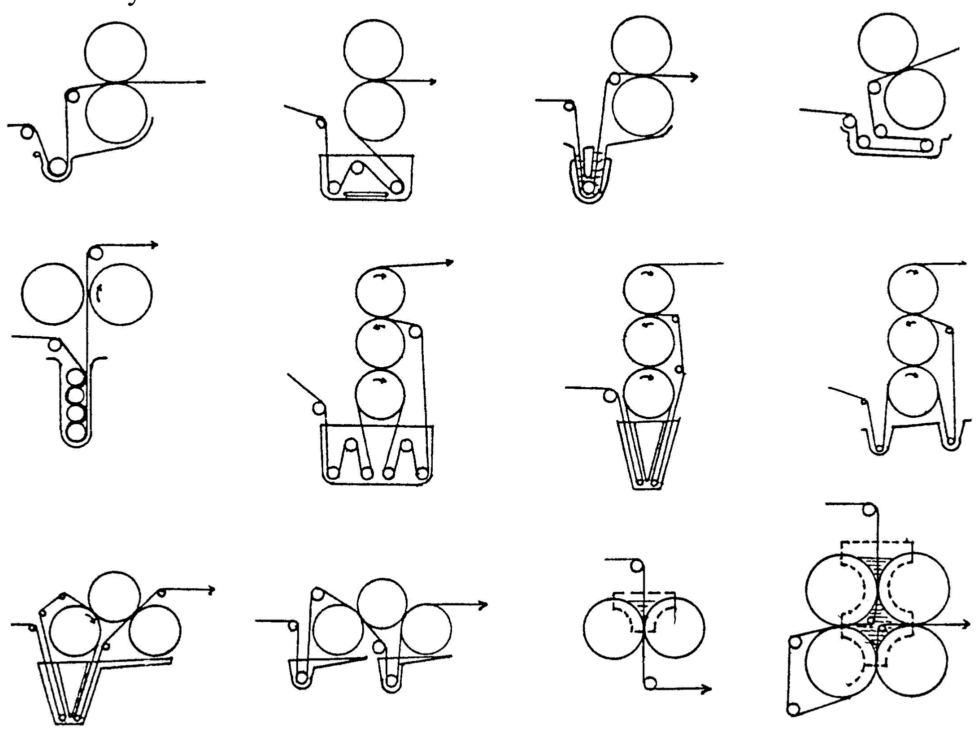
## Pad Dyeing

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 head-tail defects. 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 particularly dense fabrics) according to the affinity for dyes of the fabric and the stability of the dyebath.
The impregnation vat must be so shaped to allow the fabric an adequate contact time for absorbing the dyebath, even with a reduced capacity of the vat and a high through speed of the fabric; the reduced liquor volume facilitates a fast exchange of the liquor itself in the impregnation vat thus reducing possible head-tail 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 that a constant level of the liquor is maintained in the vat while providing a uniform impregnation.




*Picture 71 - 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.

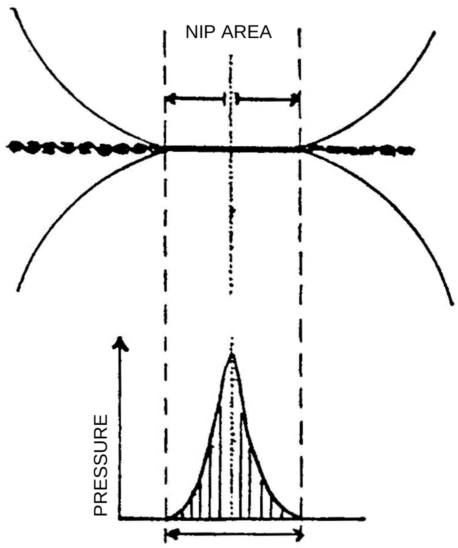


*Picture 72 – Different types of pad dyeing machines*

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 their mechanical and chemical resistance to intermolecular cross-linking levels obtained which complies with its elasticity (elastomers).

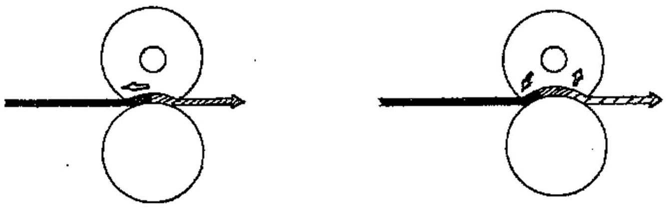
The quantity of monomers from which elastomers are obtained is very limited (approx. 10) and the characteristics of the materials used for the coating are obtained by aggregating particular chemical groups to these basic components. During the dyeing process, the elastic material, which makes up the 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.
A crucial 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 is 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 camber cylinder, i.e. 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 units of area).
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 picture. 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 unit of area 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.



*Picture 73 - Nip area between the squeezing cylinders.*

The elastic coating 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 solution easy draining from the compression area with an alternate action of compression and expansion of the pores of the elastic coating.
This cylinder works against a "hard” metal or hard rubber cylinder. 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 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.
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 defects may require a grinding treatment.



*Picture 74 – 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 with 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 on characteristics, on the fibre composition of the fabric and 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:

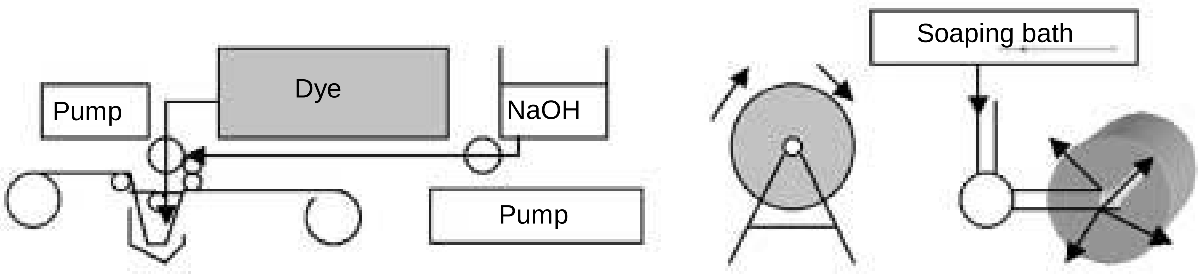
- avoid working with saturated or almost saturated solutions, which could deposit crystals on cylinders by evaporation of the solvent;
- protect the cylinders from light, ozone, chlorine vapours and from the heat (radiant heat from heat-generating media, hot air convection, etc.) above all at the end of the treatments;
- pay attention to the aggressiveness of solvents and chemical reactants used;
- 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 pad dyeing cycle 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 on the liquid, which could distort the roll and create dyeing defects. The fabric is finally washed with auxiliaries (continuous or discontinuous systems).

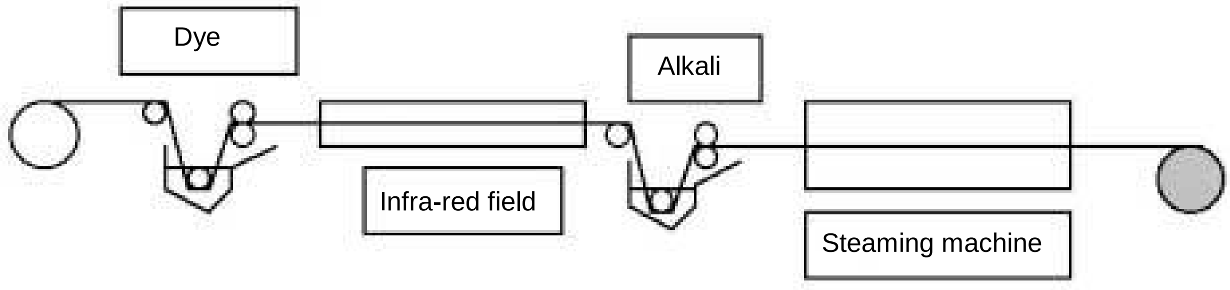



*Picture 75 - Drawing of a pad-batch system*

With the *pad-roll* system, after being soaked and heated with steam or infrared rays to obtain uniformity of dye application, the fabric is kept inside hot steaming chambers at 60-80° C, for 2 to 8 hours, depending on the dye used and on the desired colour intensity.
The *pad-jig* 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 dyebath, 5-10% of the pad dyebath is added to withstand dye bleeding.
The fabric is then washed and rinsed.

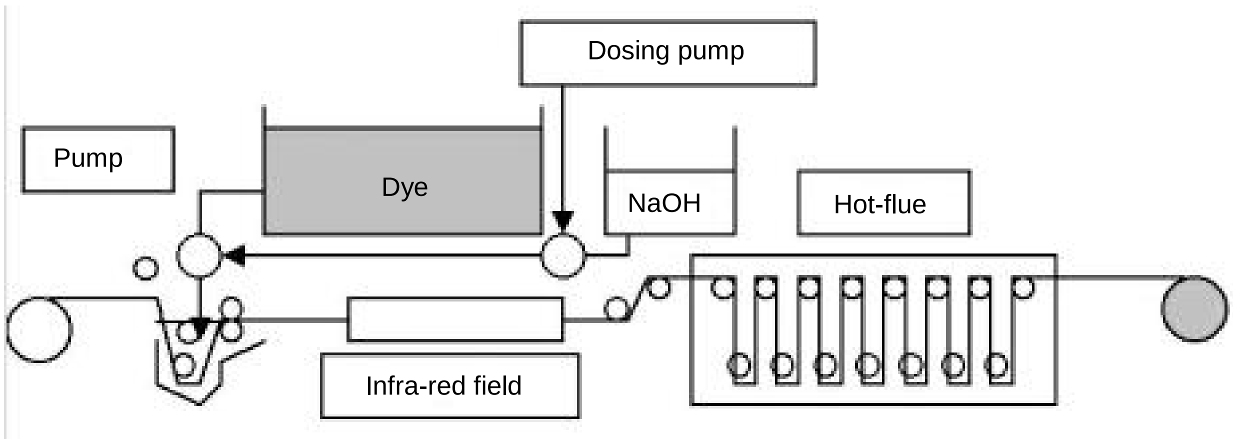
*Continuous processes*

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 dyes used.




*Picture 76 - A pad-steam system*

In *pad-dry system,* 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.




*Picture 77- Pad-dry system*

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