# A Review of Textile Dyeing Processes

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Textile materials can be dyed using batch, continuous or semi-continuous processes. The type of process used depends on several things including type of material (fiber, yarn, fabric, fabric construction, garment), generic type of fiber, size of dye lots and quality requirements in the dyed fabric.

Machinery for dyeing must be resistant to attack by acids, bases, other auxilary chemicals and dyes. Type 316 stainless steel is normally used as the construction material for all parts of dyeing machines that will come in contact with dye formulations.

### Batch Dyeing Processes

Batch processes are the most common method used to dye textile materials. Batch dyeing is sometimes called exhaust dyeing because the dye is gradually transferred from a relatively large volume dyebath to the material being dyed over a relatively long period of time. The dye is said to exhaust from the dyebath to the substrate. Textile substrates can be dyed in batch processes in almost any stage of their assembly into a textile product including fiber, yarn, fabric or garment. Generally, flexibility in color selection is better and cost of dyeing is lower the closer dye application is to the end of the manufacturing process for a textile product.

**ABSTRACT**

**Basic principles of batch and continuous dyeing processes are described in terms of the equipment used to dye a variety of textile materials. Equipment and process are selected depending on the substrate type, fiber type, size of dye lot and quality requirements. Batch (or exhaust) dyeing equipment can be subdivided into three groups depending on whether the substrate, dyebath or both are circulated. Batch equipment described includes becks, jets, jigs, package dyeing machines, beams, skein dyeing machines, paddle machines, rotary drum machines and tumblers. Continuous dyeing equipment topics include continuous dyeing of polyester/cellulose blend materials and carpet and long chain dye ranges for warp dyeing.**

**KEY TERMS**

**Batch Dyeing**
**Continuous Dyeing**
**Dyeing**
**Dyeing Machinery**
**Machinery**
**Wet Processing Machinery**

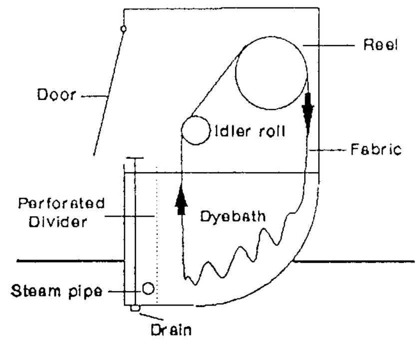


Fig. 1. Dye beck.

Some batch dyeing machines operate at temperatures only up to 100C. Enclosure of the dye machine so that it can be pressurized provides the capability to dye at temperatures higher than 100C. Cotton, rayon, nylon, wool and some other fibers dye well at temperatures of 100C or lower. Polyester and some other synthetic fibers dye more easily at temperatures higher than 100C.

The three general types of batch dyeing machines are those in which the fabric is circulated, those in which the dyebath is circulated while the material being dyed is stationary, and those in which both the bath and material are circulated. Fabrics and garments are commonly dyed in machines in which the fabric is circulated. The formulation is in turn agitated by movement of the material being dyed. Fiber, yarn and fabric can all be dyed in machines which hold the material stationary and circulate the dyebath. Jet dyeing is the best example of a machine that circulates both the fabric and the dyebath. Jet dye machines are excellent for knit fabrics, but woven fabrics can also be dyed using jet machines. The following are examples of some batch dyeing machines.

### Becks

Atmospheric becks can be used for dyeing at temperatures up to 100C. Pressurized becks are used for dyeing at temperatures higher than 100C. As shown in Fig. 1, a dye beck consists of a reservoir or trough which contains the dyebath and a reel to move the loop of fabric through the dye formulation. The liquor to goods ratio used in becks is typically 15:1 or higher although becks using ratios as low as 4:1 are available.

The dye beck is sometimes called a winch because of the winch mechanism used to move the fabric. The ends of the fabric piece to be dyed are sewn together to make a continuous loop. The reel pulls the fabric out of the dye liquor in the trough and over an idler roll. After leaving the reel, the fabric slides down the back wall of the beck and gradually works its way from the back toward the front of the machine. Several loops of fabric of about the same length are dyed simultaneously. The individual loops are separated from one another by a dividing device called the peg rail extending the width of the machine. The peg rail contains smooth pegs spaced several centimeters apart to provide an opening through which the fabric rope can pass. Loops of fabric are typically 50 to 100 meters long depending on the weight of the fabric and other factors. The number of loops processed depends on the size of a particular machine and may vary from only one loop in a laboratory or sample machine to 50 or more loops in a large production machine.

The trough is slanted at its rear to allow the fabric layers to slide down into the dye liquor and move gradually toward the front of the machine. A deep trough and steep sloping back works well for fabrics which do not crease easily while a shallower more gradual slope helps to prevent creasing. The idler roll presses some of the excess dye liquor from the fabric, improving exchange of the liquid in the fabric with formulation in the trough.

Chemicals and dyes used in the dyeing are added to a compartment at the front of the beck. The divider separating the compartment from the trough is perforated, allowing the added chemicals to gradually become mixed with the liquor in the trough.

Live steam is injected into the compartment to heat the liquor to the required temperature. The injection of steam vigor-

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ously agitates the compartment and aids in mixing the dyes and chemicals into the dye liquor. The steam injected into the beck condenses in the liquor so some dilution of the dye liquor must be tolerated.

The greatest advantages of becks are simplicity, versatility and relatively low price. Becks subject fabrics to relatively low lengthwise tension and encourage the development of yarn crimp and fabric bulk. However, becks tend to use large amounts of water, chemicals and energy. Becks can cause abrasion, creasing and distortion of some fabrics.

A continuous strand can be dyed instead of the usual multiple loops of fabric if the beck has this capability. In this system, a single long strand of fabric is gradually spiraled through the dye formulation from one side of the beck to the other. This method decreases the requirements for material handling, reduces waste and eliminates the necessity for trimming and sewing of individual loops.

### Jet Dyeing

Jet dyeing machines resemble becks in that a continuous loop of fabric is circulated through the machine. However, the cloth transport mechanism is dramatically different in these two types of machines. Fig. 2 shows a schematic diagram of a jet machine. A high speed jet of dye liquid created by a venturi transports the fabric through the cloth guide tube of the jet machine. A jet machine has a cloth guide tube for each loop of fabric being processed. A powerful pump circulates the liquor through a heat exchanger outside of the main vessel and back into the jet machine. The fabric travels at high velocity of 200-800 meters per minute while it is in the cloth guide tube. The fabric leaving the cloth guide tube enters a larger capacity cloth chamber and gradually advances back toward the cloth guide tube.

Pressurizing a jet dyeing machine provides for high temperature dyeing capability. High temperature jet machines are especially suitable for delicate fabrics made of texturized polyester. Some atmospheric machines designed for dyeing temperatures up to 100C also use the jet circulation principle.

Jet dyeing machines provide the following advantages compared to atmospheric becks for dyeing fabrics made from texturized polyester.

- Vigorous agitation of fabric and dye formulation in the cloth tube increases the dyeing rate and uniformity.
- Rapid circulation of fabric through the machine minimizes creasing because the fabric is not held in any one configuration very long.
- Lengthwise tension on the fabric is low so the fabric develops bulk and fullness of handle.
- Dyeing at high temperature of about 130C gives rapid dyeing, improved dye utilization, improved fastness properties and makes possible the elimination of carriers required when dyeing at lower temperatures.
- The lower liquor ratio used in jet dyeing allows shorter dye cycles and saves chemicals and energy.

Some disadvantages of jet dyeing machines compared to becks are as follows:

- Capital and maintenance costs are higher.
- Limited accessibility makes cleaning between dyeings and sampling for color during the dye cycle difficult.
- The jet action tends to make formulations foam in partially flooded jet machines.
- The jet action may damage the surface of certain types of fabrics.

Jet dyeing machinery evolved steadily after invention of the machine in 1961. The first machines were partially flooded. Fully flooded machines keep the fabric completely submerged during the dye cycle. This prevents the formation of longitudinal creases which occur when the fabric is lifted from the bath in a partially flooded machine. Fully flooding the machine also prevents formation of foam. The so-called "soft flow" machines use the same principle of a transport tube as a jet machine where the fabric is transported in a stream of dye liquor. However, transport of the fabric in soft flow jet machines is assisted by a driven lifter reel. These machines either eliminate the high velocity jet or use a jet having lower velocity than that used on conventional jet dye machines. The soft flow machines are more gentle on the fabric than conventional jet machines. Jet machines offering

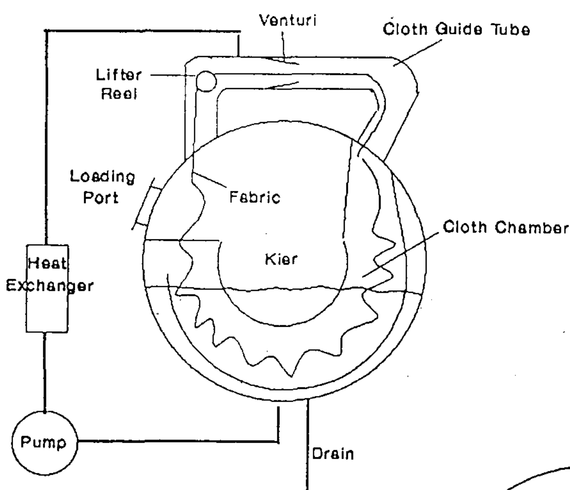


Fig. 2. Jet dyeing machine.

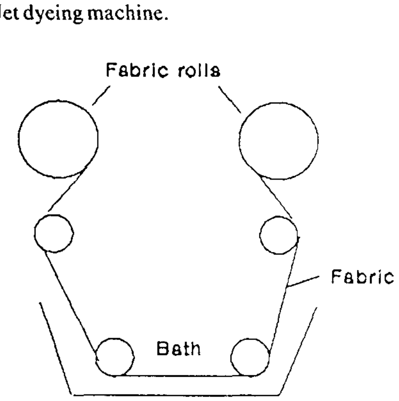


Fig. 3. Dye jig.

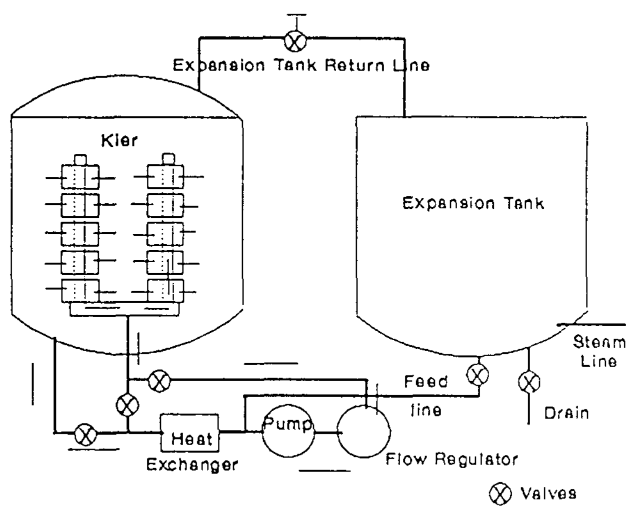


Fig. 4. Package dyeing machine.

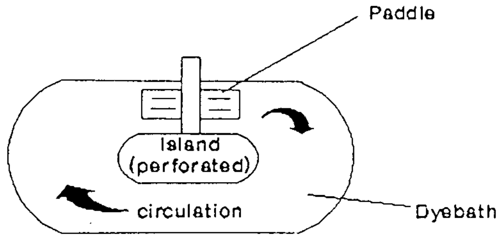


Fig. 5. Side paddle dyeing machine, overhead view.

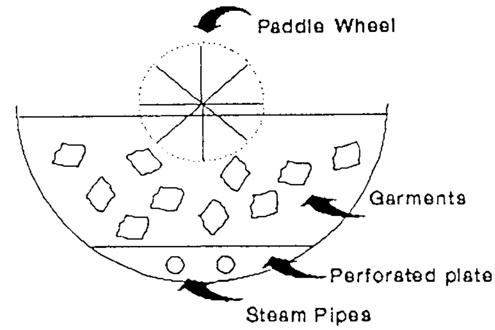


Fig. 6. Paddle dyeing machine.

capability of very low liquor ratios of about 5:1 are also available.

**Jigs**

As shown in Fig. 3, a jig consists of a trough for the dye or chemical formulation. The fabric from a roll on one side of the machine is run through the formulation in the trough and wound on a roll on the opposite side of the jig. When the second roll is full, the drive is reversed, and the fabric is transfered through the formulation back to the first roll.

Live steam injected into the bottom of the trough through a perforated pipe across the width of the jig heats the formulation. Closed coils containing high pressure steam can also be used to heat a jig. Live steam heats the formulation faster than closed coils but dilutes the formulation. Automatic devices control temperature and reverse the direction of the fabric when required on modern jigs.

A dye jig is normally used for dyeing at pressure of one atmosphere although pressurized, high temperature jigs have been made. Covering the top of a jig minimizes heat loss to the atmosphere, keeps the temperature uniform on all parts of the fabric and minimizes exposure of the formulation to air. Minimizing exposure to air is most important when using sulfur and vat dyes since these dyes can be oxidized by atmospheric oxygen.

Maximum batch size on a jig may be up to several thousand meters of fabric. Jigs exert considerable lengthwise tension on the fabric and are, therefore, more suitable for woven than for knit fabrics. Since the fabric is handled in open width, a jig is very suitable for fabrics which crease if dyed in rope form.

**Package Dyeing**

The term package dyeing usually refers to dyeing of yarn which has been wound on perforated cores so that dye liquor can be forced through the package. Packages may be tubes, cheeses or cones. Cores for dye packages may be rigid stainless steel, plastic or paper. Plastic and paper types are normally intended to be used only once while stainless steel cores can be reused indefinitely. Plastic and paper cores as well as stainless steel springs are used as compressible cores. These compressible cores allow more packages to be forced into the dye vessel and increase the capacity of the machine.

As shown in Fig. 4, the yarn packages are placed on perforated spindles on a frame which fits into a pressure vessel where dyeing takes place. The dye vessel is cylindrical and has domed ends. The top cover, which must be removed for loading and unloading, is secured during dyeing by bolts or a sliding ring which can be quickly locked. Most package dyeing machines are capable of dyeing temperatures up to 135C. The number of packages may vary from as few as one in a laboratory machine to several hundred in a large production machine.

The dye formulation is pumped through the perforations in the spindles and package cores into the yarn. The flow of liquid can be either from inside-to-outside of the package or outside-in. Periodic reversal of the direction of flow improves uniformity of dyeing.

A package dye machine has an expansion tank mounted alongside the dye vessel. The expansion tank accomodates the increased volume of dyebath resulting from thermal expansion when the bath is heated. Chemical and dye adds are made to the vessel through the expansion tank.

A heat exchanger using high pressure steam as the heat source heats the dye liquor in a package dye machine. The steam coils for heating the liquor are also used as cooling coils after the dye cycle is completed.

Liquor ratio in a package dye machine is typically about 10:1 when the machine is fully loaded. Use of lower liquor ratio can save water, energy and chemicals. The liquor ratio can be lowered by only partially flooding the machine. If the liquor covers all of the packages but does not fill the top dome of the machine, the liquor ratio is only slightly lower than it is in a fully flooded machine. If only the base of the carrier is covered with dye solution, the liquor ratio may be as low as 4:1. However, the direction of liquor flow can only be inside-out using this arrangement. High quality dyeings may be more difficult to achieve at very low liquor ratio in package dye machines.

Raw stock, tow and other materials can be dyed using the same principles as package dyeing. A basket (cage) is nor-

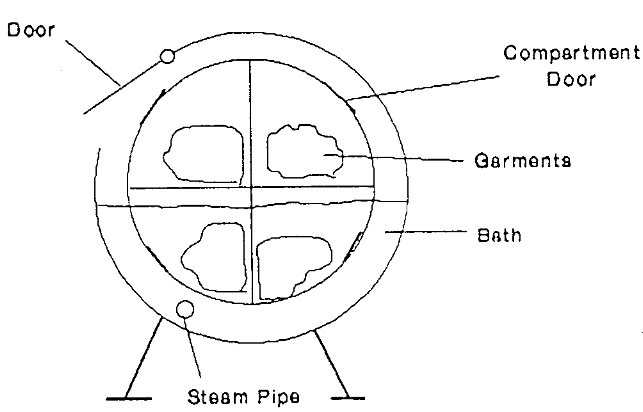


Fig. 7. Rotary drum dyeing machine.

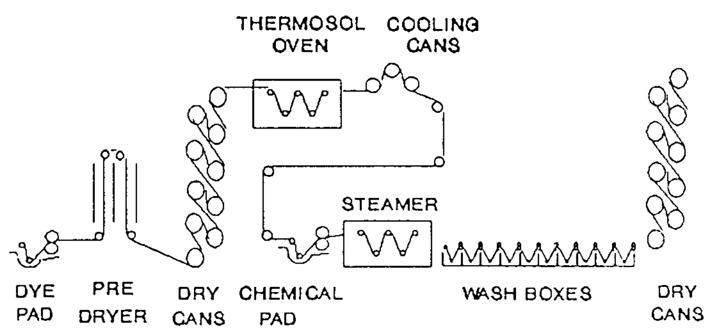


Fig. 8. Schematic diagram of a continuous dyeing range.

mally used to hold these materials during the dyeing.

### Beam Dyeing

The principles of beam dyeing are essentially identical to those of package dyeing. Either yarn or fabric can be beam dyed. The fabric or yarn is wound on a perforated beam. A beam machine can be designed to hold a single beam or multiple beams in a batch. Beam dyeing of warps is practical in producing patterned fabrics where the warp yarn will be one color and the filling will be another color.

### Skein Dyeing

In skein dyeing (also called hank dyeing), skeins of yarn are mounted on a carrier which has rods (sticks) at the top and bottom to hold the skeins. The skeins are suspended in the dye machine and dye liquor is gently circulated around the hanging skeins. Perforated plates can be used at the top and bottom of the machine to help provide uniform flow of the dye liquor. Alternatively, the dye liquor can be pumped through perforations in the sticks so that it cascades down over the hanging skeins. Skein dyeing produces good bulk in the yarn because of the low tension on the yarn in the dyebath. The method is used mainly for bulky yarns like acrylics and woolens for knitted outerwear and hand

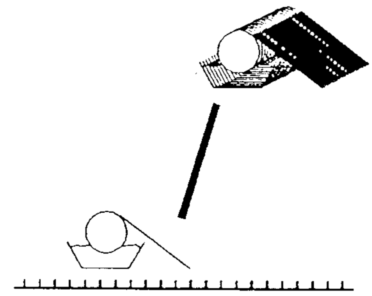

Fig. 9. Example of dye applicator for continuous carpet dyeing machine.

knitting. Woolen carpet yarn is sometimes skein dyed.

Skein dyeing uses a high liquor ratio and a lot of energy. Uniform dyeing is difficult to achieve in a skein dyeing machine. Slow winding and backwinding requirements of the process make it labor intensive. Package dyeing has replaced some skein dyeing even though the yarn bulkiness achieved in skein dyeing is usually not matched in package dyeing.

### Paddle Machines And Rotary Drums

Paddle machines and rotary drum machines can be used to dye textiles in many forms, but these two methods are used mostly to dye garments. Steam injection directly into the dyebath heats both of these types of machines. Schematic diagrams of side paddle and overhead paddle dye machines are shown in Figs. 5 and 6. The side paddle machine is shown from the top since this gives the best view of the location of the parts of the machine. The paddle circulates the bath and garments around a perforated central island. Chemicals, water and steam for heat are added inside the perforated central island. The overhead paddle machine is simply a vat with a paddle having blades the full width of the machine. The blades dip a few centimeters into the vat to stir the bath and push the garments down, keeping them submerged in the dye liquor.

A rotary drum machine is a cylindrical vessel slightly larger than its internal perforated drum which holds the material to be dyed. The perforated drum is divided into several chambers each having its own door through which it can be loaded and unloaded. The drum rotates horizontally as shown in Fig. 7. Rotary drum machines are commonly used to dye hosiery.

### Tumblers

Tumblers are very similar in principle to rotary drum machines except that they are usually larger. They also resemble large commercial drycleaning machines. Tumblers have a perforated drum which rotates inside a larger vat which contains the dye or chemical formulation. The drum can be divided into compartments to assist in agitating the garments, or baffles around the periphery of the drum serve to tumble the garments in the dye formulation. These machines extract some of the water by centrifugal action after completion of the dyeing. Tumblers are used for dyeing garments and for wet processing (prewashing) garments dyed with indigo. Modern machines of this type are usually equipped with automatic controls and some are designed to tilt forward to provide for easy loading and unloading of batches of garments.

### Continuous dyeing processes

Continuous dyeing is most suitable for woven fabrics. Most continuous dye ranges are designed for dyeing blends of polyester and cotton. Nylon carpets are sometimes dyed in continuous porcesses but the design of the range for continuous dyeing of carpet is much different than that for flat fabrics. Warps can also be dyed in continuous processes. Examples of warp dyeing are slasher dyeing and long chain warp dyeing using indigo.

### Polyester/Cellulose Blends

A continuous dye range is efficient and economical for dyeing long runs of a particular shade. Tolerances for color variation must be greater for continuous dyeing than batch dyeing because of the speed of the process and the large number of process variables that can affect the dye application. The process as shown in Fig. 8 is often designed for dyeing both the

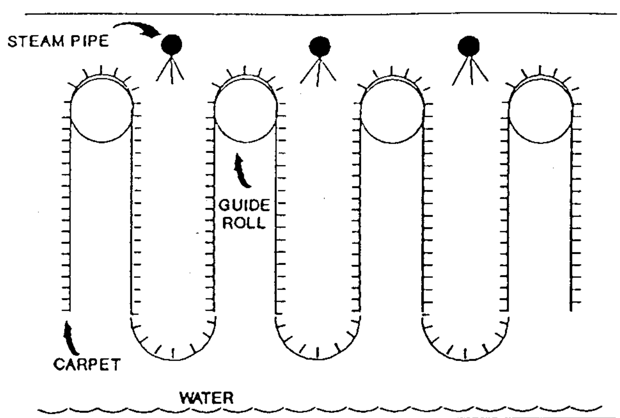


Fig. 10. Loop steamer for continuous carpet dyeing machine.

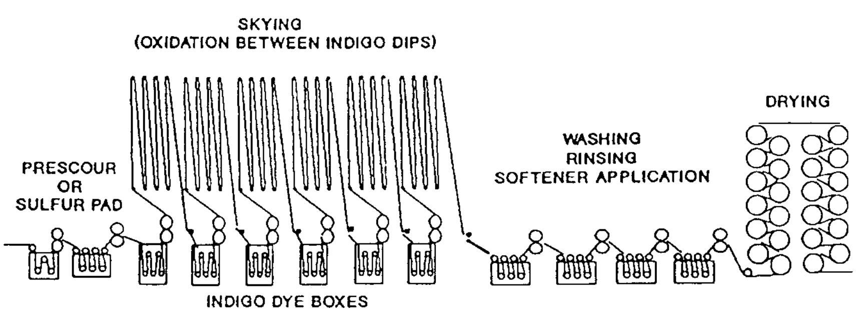


Fig. 11. Schematic diagram of long chain dyeing range.

polyester and cotton in a blend fabric in one pass through the range. The polyester fibers are dyed in the first stages of the range by a pad-dry-thermofix process. The cellulosic fibers are dyed in the latter stages of the range using a pad-steam process.

Fabric previously prepared for dyeing enters the dye range from rolls. A scray is used to accumulate fabric entering the range so that the range can continue to run while a new roll of fabric is sewn to the end of the strand being run. Uniformity of application of dye requires that continuous dyeing be done in open width. Typical line speed in a continuous dyeing process is 50 to 150 meters per minute.

Padding is a critical step in continuous dyeing. The disperse dye formulation (and sometimes the dyes for the cellulosic component) is applied in the first padder. The fabric is immersed in the dye formulation usually at room temperature and squeezed to give a uniform add-on of dye formulation across the width and along the length of the fabric. Low temperature in the formulation in the padder minimizes tailing. Higher temperature promotes wetting of the fabric in the short time the fabric dwells in the pad formulation.

The wet fabric leaving the padder enters a dryer to remove moisture and leave the dye uniformly deposited on the fabric. Radiant predrying using infrared energy inhibits migration of the dye. Drying is completed using steam-heated cylinders.

A thermal treatment called thermosoling fixes the disperse dye on the polyester fibers. The thermosol oven heats the fabric to a temperature of 390-430C, the exact temperature depending on the particular dyes being applied. The dye sublimes and diffuses into the polyester fibers during the thermosol treatment. The fabric dwells in the thermosol oven for about one to two minutes.

The cooling cans lower the fabric temperature so that it does not heat the solution in the chemical pad. The chemical padder applies the dyes (and sometimes chemicals) for the cellulosic fibers.

The steamer heats the wet fabric so that the dye can diffuse into the cellulosic fibers. The fabric usually dwells in the steamer for 30-60 seconds.

The washing section of the range is used for rinses, chemical treatments which may be required to complete the dyeing, and washing of the fabric to remove unfixed dye and auxiliary chemicals used in the dyeing. The dye and chemical formulations used in the padders and washboxes depend on the particular classes of dye being applied.

### Continuous Dyeing of Carpet

A continuous dye range for carpet consists of a dye applicator and steamer. The process is designed for application of acid dyes to nylon. Carpet manufacturers are innovative in application of dye to produce special color effects on their product. As a result, many variations of dye applicators exist. A very high liquor ratio is normally required to produce good quality dyeing of carpet. As shown in Fig. 9, a typical application method is to meter the dye solution onto the surface of the carpet. The stream of dye being metered onto the carpet can be momentarily interrupted to produce patterned effects. Streams of different color dyes can be applied in different patterns to produce special effects.

Loop steamers are used in continuous carpet dyeing so that the carpet always faces away from the guide rollers. As shown in Fig. 10 this festooning of the fabric prevents compression of the carpet pile by rollers in the steamer.

### Long Chain Dye Range

Warp yarns are often dyed with indigo and sulfur dyes using a long chain dye range. The process is used where the warp will be one color and the filling another color, as in denim fabrics. A schematic diagram of the process is shown in Fig. 11. Ball warps (sometimes called "logs" because of their cylindrical shape) are prepared as supply packages for the long chain dye range. A ball warp is a warp in which several hundred warp yarns are condensed into a rope and wound as a single strand into a ball (log). The yarn from each ball warp constitutes a continuous rope (chain). A long chain dye range accommodates multiple ropes or chains side-by-side so that thousands of yarns are being dyed simultaneously. After exiting the long chain dye range, each rope is taken up in a separate container. After dyeing, each individual warp is backwound onto a warper beam (section beam) and becomes a supply package for the slasher.

Long chain dye ranges usually have a wet-out box to wet and partially scour the yarn before it enters the dye application section of the range. The range contains a series of dye boxes which are designed to apply indigo. Indigo has low affinity for cellulose and must be applied in several stages called dips. Each stage consists of immersing the yarn in a solution of the reduced indigo, squeezing to remove excess solution, and skying to allow air to oxidize the dye and make it insoluble. The shade gets progressively darker at each dip. The dye boxes are large and a circulation system involving all of the boxes is used to keep the indigo solution mixed well and prevent tailing of the shade.

A sulfur dye can be applied either before the indigo, giving a sulfur bottom, or after the indigo to give a sulfur top. The use of a sulfur dye reduces the amount of the more expensive indigo needed to produce the shade and may also modify the fastness properties as required for a particular use of the fabric.

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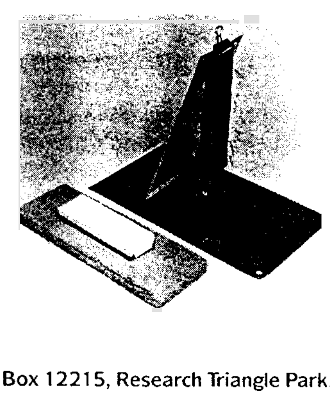

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