Chapter 7

BLEACHING AND WASHING EQUIPMENT

7.1 Introduction

Textiles can be bleached and washed in loose form, yarn form and fabric (woven and knitted) form. Loose stock can be bleached by steeping method in a suitable vessel. Yarns and tops are bleached using skiens or package machines. Knit goods are commonly scoured and bleached in comparatively small batches in winch and jet machines [1, 2]. However, continuous bleaching ranges for cotton knit goods are available. Rotary machines can be used for bleaching of hosiery fabrics. Woven fabrics can be bleached in three different ways, such as batch process (kiers), semi-continuous process and continuous process. In the semi-continuous process, pad-batch and pad-roll systems and in continuous process, rope or open-width J-Boxes are popular. Over the past few years, there have been new open-width continuous machineries designed, developed and installed in the modern bleach house and have made efficient impression in the industry.

7.2 Batch Bleaching Process Machineries

In the earlier days bleaching of woven piece goods was usually carried out by piling the material into glazed brick or tile lined tanks containing hypochlorite solutions. The usual practice is to turn the load into an adjacent second tank, so that the end which entered first is also drawn out first. The bin or pits have false bottom which allows drainage of bleaching solution. The cloth is allowed to dwell there until the bleaching is complete.

Bleaching of cotton, linen, rayon, man-made fibres etc. in the form of woven or knitted fabrics, hanked yarns and loose stock with appropriate bleaching agents can be carried out in pack bleaching ranges (Fig. 7-1) or in kiers. The bleaching tanks can be fully enclosed or open type equipped with automatic temperature control and the entire process can be programmed control. The capacity of the machine may be 200-2000 kg goods. There is an arrangement of automatic plaiter to pile the fabric ropes (Fig. 7-2). This ensures even twistless piling of fabric ropes at all speeds, regardless of fabric weight. Rail is mounted to serve several tanks seperately. After the bleaching solution is added sufficient water is added to ensure that the load is completely immersed. The temperature is raised to the required tempera-

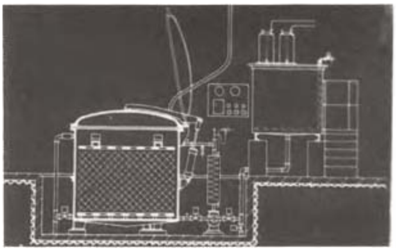


Figure 7-1. Pack bleaching ranges (Courtesy of Friedrichsfeld, Germany).

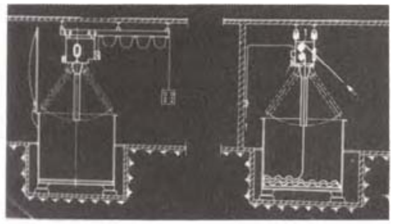


Figure 7-2. Automatic rope piler for circular tanks.

ture, the bleach liquor is sprayed from the top and the liquor percolates through the batch continuously. In the liquor circulating system only 2 h may be necessary, but longer time is required for open kier type of machineries. After bleaching, the goods may be washed in the same machine itself, preferably with warm water, then put through a rope washer.

Raw stocks and yarns in packages or in beams can be bleached only by the liquor circulating machines. Cotton yarn in the form of hank can be bleached as a rope of cloth using pressure kiers, washing machines and hypochlorite bleaching pits. But the modern tendency is to bleach in a more efficient manner in dyeing machines in the form of beams (Fig. 7-3) and packages (Fig. 7-4). This machine

Figure 7-3. Universal HT dyeing and bleaching machine (Courtesy of Argelich, Teames & C.A., Spain).

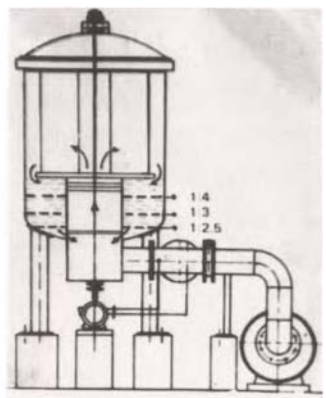


Figure 7-4. Rapid low liquor ratio package dyeing and bleaching machine [3].

(Fig. 7-3) is suitable for dyeing and bleaching of loose stock and yarn as well as of warp beams, tops and carded sliver. All known natural and synthetic fibres can be treated. The cylindrical, vertical autoclave is lifted with a central, conical support for the material carrier, as well as with a drain valve. The cover is lifted with a rapid lock. Counterweight springs assist easy opening and closing of the lid. The main line of development in package dyeing machines (Fig. 7-4) has been the ability to dye and bleach at high temperature and pressure with greatly improved liquor flow. The alkali scour and hypochlorite process is not particularly suitable for yarn in such forms. A single stage peroxide bleaching and for full white double peroxide bleach may be required.

In the past it has been and still is common practice to use mainly winches or jet machines for preparatory of both woven and knitted fabrics in tubular form. Starting with the winch beck, machineries for pre-treatment processes have passed through several stages of development (jig, beam, jet, overflow), some paralleled in washing machines. The current trends towards smaller series have led to a comeback of the conventional systems using jigger machines (Fig. 7-5) for textile processing.

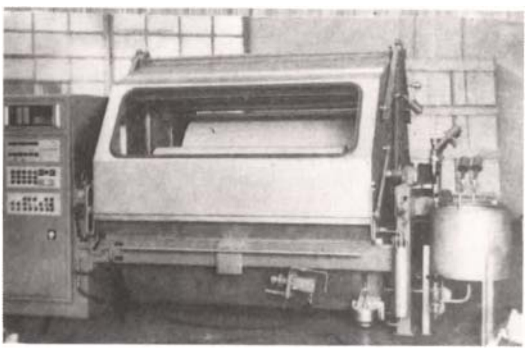


Figure 7-5. Automatic jigger offering maximum automation and enhanced quality (Courtesy of Mezzera-Kleinewefers S.p.A., Italy).

Now-a-days, old obsolete hydraulic jiggers are replaced by new models capable of working with constant fabric tension and adjustment ranging from 1 and 500 Nw/m with a maximum working speed up to 150 m/min. Where batched size is around 6000 m, jumbo jiggers and pressurised jumbo jiggers [Fig. 7-6(b)] can be used for bleaching in open-width form. In non-pressurised jumbo jiggers [Fig. 7-6(a)] prepa-

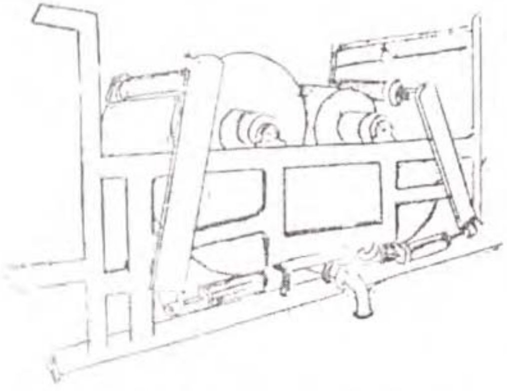


Figure 7-6(a). Open super Jumbo Jigger.

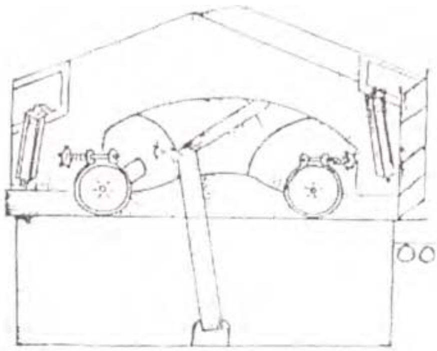


Figure 7-6(b). Pressurised Jigger.

ration of cotton fabric does not yield a satisfactory performance, though this is adequate for polyester/cotton blends.

Most knitted goods are batched process in winches which operate up to 140°C under pressure in an autoclave with usual fittings. The entire sequence of operations can be program controlled. In the modern winch machines (Fig. 7-7) the fab-

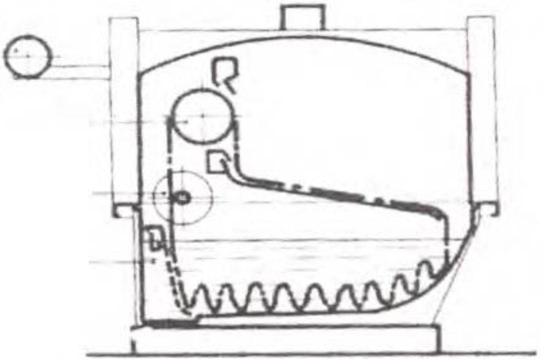


Figure 7-7. Winch machine.

ric runs through in 30 sec as against the 3-4 min otherwise required, and also penetration is excellent. The fabric is propelled by a winch in conjunction with bath circulation. Maximum liquor ratio is 10 : 1. Such batch processes are made continuous with the development of 'spiral' winches and 'spiral' jets [4-6]. Scouring and bleaching performance has been considerably improved with the novel rope washing machine (Fig 7-8), in which tubular fabric is moved through the machine

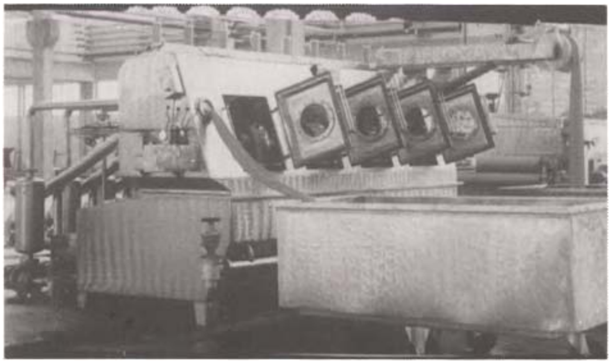
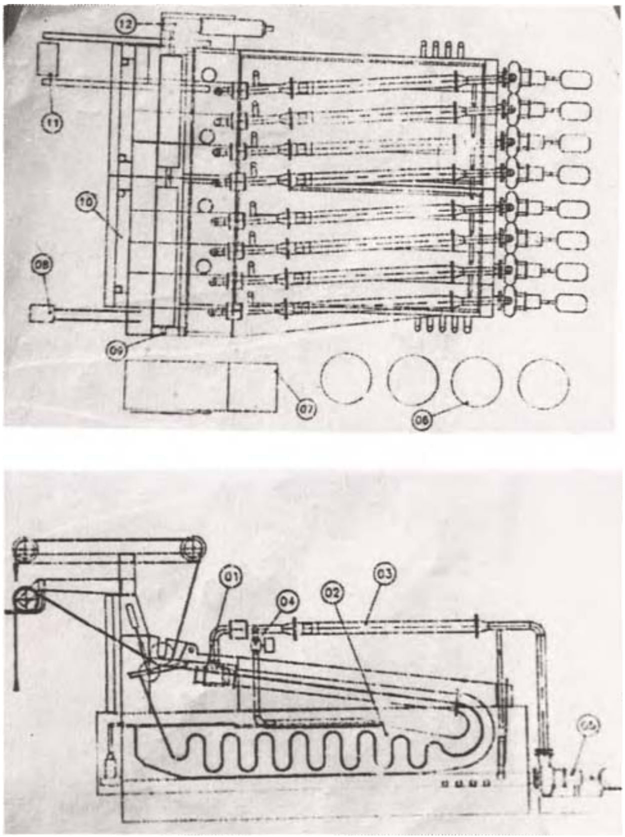


Figure 7-8. Novel counterflow rope treatment machine (Courtesy of MCS, S.p.A., Italy).

in a sprial fashion. The new ranges are primarily intended for prewashing, bleaching and afterwashing of knitted and woven fabrics in rope form. They can comprise 6 or 12 washing sections connected in series, a guide roller, a rotary pulsator fitted with several individual milling rollers, a heat recovery unit and a fabric feed and delivery system in a stainless steel housing. The washing sections each have an inlet and outlet and are interconnected by a flexible tube round the rotary pulsator. The fabric is drawn into the machine by means of a transport roller and fed to the individual washing sections. The latter are connected so that fresh water can be supplied to the entire machine on a counterflow principle. There is provision of metering the chemicals and the necessary textile chemicals can be added in controlled quantities and the correct processing temperature can be maintained for the individual washing sections. The process control technology stores all machine and process cycle data and makes overriding operating data logging units accessible via profibus.

Another one is spiral jet bleaching unit in which the woven and knitted fabrics can be pre-treated as shown in Fig. 7-9. In this machine, the fabric is moved in a spiral, in rope form, through the tube, using jets that lifted the fabric out of one compartment and deposited in the next [7-9].

A comparison of typical bleaching recipes of cotton fabric for batch bleaching in different equipment with hydrogen peroxide is summerised in Table 7.1. When making-up a bleaching bath, naturally the quality of cotton, degree of pre-treatment, liquor ratio, equipment used and temperature must all be taken into account.



1. Jet
2. Channel
3. Heat exchanger
4. By-pass
5. Circulation pump
6. Side tank
7. Control panel
8. Loading winch
9. Rolls
10. Doors
11. Unloading winch
12. Drive

Figure 7-9. Spiral jet bleaching unit (Courtesy of Küster KBR).

7.3 Semi-Continuous Bleaching Process Machineries

Both peroxide and sodium chlorite can be used for bleaching of cotton and polyester/cotton goods by semi-continuous open-width form. In the pad-batch (or pad-stack) process the padded goods are batched and then covered with plastic sheet to prevent evaporation of bleaching agent or gas and then allowed to lie for 24 h. In the pad-roll process (Fig. 7-10), the goods after padding with bleaching solution are then heated in a steam chest and rolled-up in a mobile batch chamber for 4-12 h. The chamber can be sealed so that no gas can evolve during bleaching.

TABLE 7.1
Comparison of Bleaching Recipes for Various Batch Processes

Form of material	Fibre, Stock	Yarn	Fabric	Fabric	Knitted fabric	Hosiery
Machine used	Circulating machine	Package m/c	Kier	Jig	Beck	Rotary
L:m	8:1	10:1	6:1	1:1	6.6:1	20:1
Amount of H_2O_2 (35%)						
(o.w.f.), %	3-4	5-10	0.5-1.5	1.17-2.34	3.5	1.4-2.2
On weight of solution						
(o.w.s.), %	0.37-0.5	0.5-1	0.8-0.25	-do-	0.53	0.7-1.1
Sodium silicate						
o.w.f., %	3.5	4.0	1-3	0.84-1.33	–	1.8
o.w.s., %	0.44	0.4	0.17-0.5	-do-	–	0.9
Sodium carbonate						
o.w.f., %	1.0	1.0	–	–	–	–
o.w.s., %	0.125	0.1	–	–	–	–
Trisodium phosphate						
(o.w.f.), %	–	–	0.25	–	–	–
Sodium hydroxide						
o.w.f., %	–	0.5	0.06	0.04	3.0	–
o.w.s., %	–	0.5	0.01	-do-	0.45	-

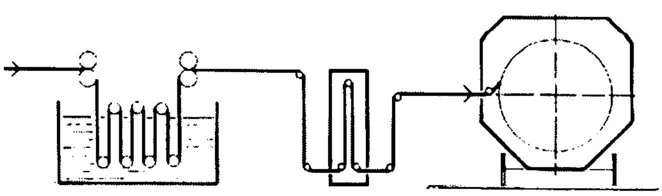


Figure 7-10. Pad-roll range.

Generally, the goods in open-width form are padded (100% expression) with either 4.3% H_2O_2 (35%) along with usual chemicals or with sodium chlorite (10 g/l) containing soda-ash (1 g/l) and wetting agent (3 g/l). It is not essential to use acid chlorite solutions in this process where effective liquor ratio is low and thus neutral chlorite solutions are suitable. However, for a longer bleaching time, a small amount of soda-ash is useful to maintain the stability of the bath. The roll is rotated gently during its dwell period. The procedure is followed by a hot wash with 1% soda-ash in the case of H_2O_2 and antichlor treatment with bisulphite in the case of sodium chlorite and then soaping the goods in a bath at about 80°C. The pad-jig process is also used for the bleaching of textiles. These systems are simple to operate but have some disadvantages like impairment of the levelness of pre-treatment due to variation in dwell time and temperature from batch to batch. However, machineries with easy and automatic batching and unbatching systems are developed with special features for the various pre-treatment and bleaching plant.

7.4 Continuous Bleaching by J-Box Systems

The main purpose of the continuous bleaching system, whether in the rope form or in open-width form, is to reduce the time of bleaching and the cost of labour involved. Continuous bleaching in J-Box in rope form was started in the late in 1930s with the introduction of hydrogen peroxide [10, 11] and plant scale equipment had been built and a suitable procedure was developed [12]. In 1942, the unit used in the bleach range was called a J-Piler [13], but by 1952 the name had become J-Box and bleacher's dream of one-step process had finally come true [14].

The heart of the process is the J-Box storage unit and the shape is like the English letter 'J'. In rope bleaching the fabric is pulled together to form a somewhat circular mass, which is loose enough for penetration and resembles a large rope ; in open-width form the fabric is under tension and is flat and smooth. J-Boxes, whether open (Becco type) or closed (Du Pont type) can both be used for pre-treatment. In the Becco type (Fig. 7-11), the cloth is piled cold into the top and is heated as it passes down through the box by steam and passed through the perforated plates around the box, just below the top of the pile. Two heating positions are provided, the lower one for use when the box is being filled. In the Du Pont type of J-Box units (Fig. 7-12), the fabric passes through the long entering box which enables the fabric rope to reach the desired temperature (98°C) before piling down into the top of the J-Box itself. The internal surface of the entire J-Box is ground very smooth to avoid any friction on the moving cloth. The material of construction of J-Box should be high quality stainless steel for peroxide treatment, fibre glass reinforcement plastic for hypochlorite treatment, stainless steel with titanium component

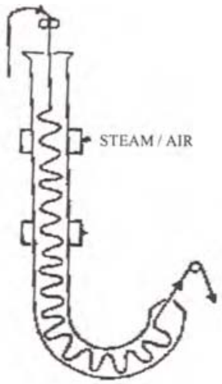


Figure 7-11. Opern-top J-Box system (Becco type).

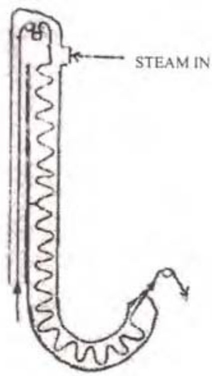


Figure 7-12. Closed-top J-Box system (Du-Pont type).

with sodium chlorite bleaching and special high molybdenum stainless steel for all treatments consisting of chlorite solutions. The J-Box may store up to 2500 yds of continuously moving goods.

Many modifications of the continuous bleaching sequences have been suggested [15]. Fig. 7-13 shows a typical three-stage (singe → desize → scour → bleach →

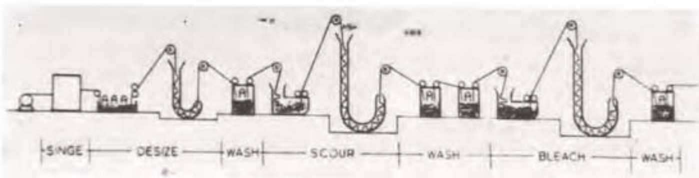


Figure 7-13. Operating sequence of a three-stage rope range.

wash) rope range sequence in a continuous J-Boxes bleaching plant. The energy conservation is a major factor in multi-stage processing and hence considerable importance has been given to the development of modified routes, first by combining scouring with desizing or bleaching. Fig. 7-14 shows the Du Pont two-stage (singe → desize → scour & bleach → wash) bleaching range. In this range the cloth in rope form is saturated with 2.5-4% caustic soda solution at 30°C and squeezed to 100% pick-up. The cloth is then rapidly heated to 100°C and piled in J-Box for about 1 h. The goods are then saturated with 0.5-1 volume peroxide solution of pH 10.6 to 10.8 in presence of sodium silicate (1-1.6%). The fabric after squeezing is

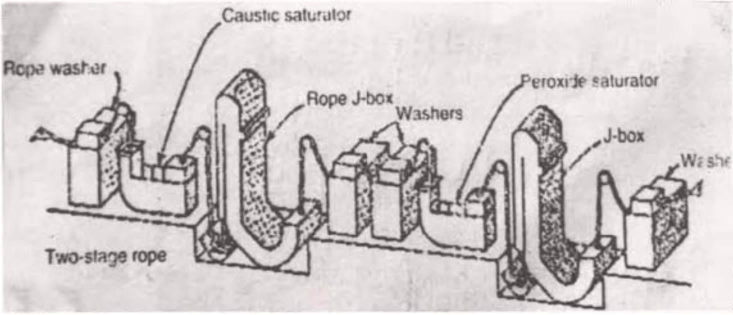


Figure 7-14. Du Pont continuous two-stage bleaching range [16].

once again heated to 100°C in the heater tube and stored for 1 h in J-Box. Goods containing dyed yarn are heated at slightly lower temperature. Finally, the goods are washed in a rope washer. Bleaching with hypochlorite can also be done using J-Box system with saturator. The fabric after saturation with hypochlorite solution containing 0.75 g/l non-ionic wetting agent and 0.25 g/l of 15% chemic at room temperature are piled into J-Box for 15-40 min at 60-100°C and then washed. The two-stage plant with a speed of about 100 yds/min requires treatment of about 2 h and also proper time and pH is required to be maintained to control the rate of reaction which may damage the cloth. Thus, in one-stage continuous rope bleaching ranges (Fig. 7-15), one more stage is eliminated and the goods are caustic treated

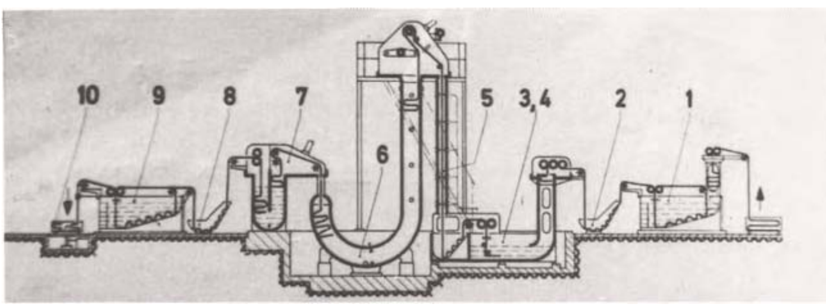


Figure 7-15. One-stage continuous rope bleaching range using J-Box (Courtesy of Friedrichsfeld GmbH, Germany).

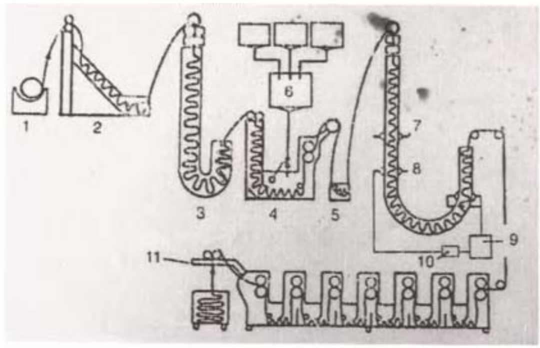
and bleached in one bath. The sodium chlorite method is often the only feasible procedure for bleaching blends of cotton and synthetic fibres by one stage system. The wetting and rinsing unit (1) is made up of three compartments, each with its own squeezing unit. Before entering the next stage the goods are deposited on a chute (2) coated with PTFE in the impregnating machine (3), liquor uptake is kept constant at about 30% by means of squeeze rollers. The impregnating liquor is circulated and filtered continuously, and the concentration of chemicals is measured and topped up automatically (4). In the heating up and shrinkage unit (5) the goods are heated to 98°C by spraying with saturated steam and piled into the J-Box (6). After exiting from the J-Box, the goods are conveyed loosely and without creasing to a water and neutralising bath by a winch forming part of the washing and neutralising section (7). The rope is squeezed only when cooled and then deposited in another intermediate store (8). The following section of the range is used to apply fluorescent whitening agents and all compartments are fitted with their own squeeze units. On leaving the range, the rope is piled into a trolley (10) for loading into a centrifuge. The concentrations of bleaching bath are given in Table 7.2. If hydrogen peroxide is used as a bleaching agent, the fabric is saturated with a

TABLE 7.2
Recipe for One-Stage Bleaching with Sodium Chlorite

Additives	Cotton	Polynosic/Cotton	Polyester/Cotton
Sodium chlorite (80%), g/l	12-20	12-15	10-12
Bleaching auxiliary, g/l	5	5	5
pH (with formic acid)	3.8	3.8	4.0
J-Box dwell period, min	90-105	60	60

solution containing H_2O_2, wetting agent, sodium silicate, caustic soda, softeners and whitening agents. The process, operated by two men at up to 200 yds/min can turn out about 10,000 yds of fabric an hour.

In the case of knitted goods, peroxide bleaching on either FMC wet bottom J-Box (Fig. 7-16) or on the Gaston County DuBec system (Fig. 7-17) are suitable. Such ranges (Fig 7-16) consist of an unwind cradle, a sewing scray, a dry storage J-Box, holding about 900 kg of tubular fabric, a saturator, a bleach J-Box and a washer. The FMC system has a wet bottom created by having a 540 litre heel tank of liquor, which is made by dropping 270 litre of the saturator liquor to it, making



1. Cradle
2. Sewing scary
3. Dry J-Box
4. Saturator
5. Wet scray
6. Mix tank
7. Air/steam mixture
8. Wet J-Box
9. Heel tank
10. Pump
11. In-line washer

Figure 7-16. Wet bottom J-Box.

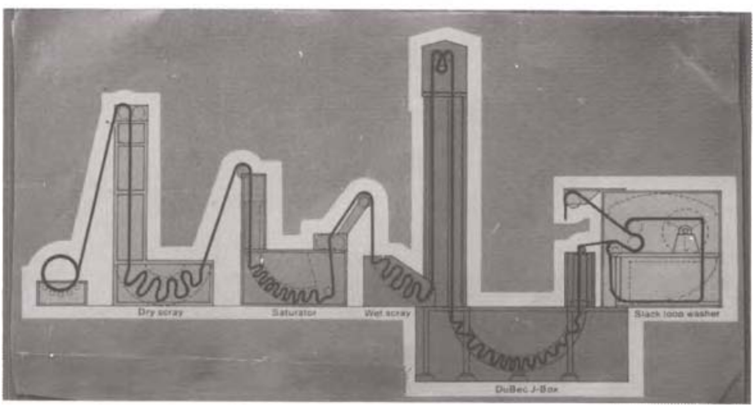


Figure 7-17. The Gaston County DuBec system.

up to 540 litre with water and circulating the liquor by means of pump inside the J-Box. In contrast, in the DuBec system (Fig. 7-17), the bleaching J-Box has a PTFE lining and the washer is a spiral rope washer. This dry storage J-Box is run 20% faster than the wet J-Box and any variation in load in the system is accomodated with compensating or balanced scrays. The DuBec range combines the best features of two well-known processes : the Du Pont single stage method and the Becco Wet heel J-Box method. Capacity of the DuBec's J-Box is 3,000 pounds. Range speeds from 50 to 150 yds /min with a production averages of about 2000 lbs/h. The J-Box recipes for the two types are compared in Table 7.3. Kolmer describes

TABLE 7.3

J-Box Recipes (100% Pick-up , Steam 90 Minutes at 90°C)

Chemical	FMC	Du Pont
Wetting agent (g/l)	5	5
DTPA, 40% (g/l)	1	1
Sodium silicate, 79°Tw (g/l)	10-20	10-20
Sodium hydroxide, 100% (g/l)	7-10	4-7
H_2O_2, 35% (ml/l)	45	45

a development of the Galaxy which uses J-Boxes for storage and washes the fabric as a flattened ''open-width' tube. Each section of the washer (the Tubolavar) consists of a small J-Box in which the flattened tubes are spray washed. On emerging from the J-Box the tube is inflated, to alter the crease location, and nipped, before going into the next section.

The follwing are the advantages and disadvantages of continuous rope bleaching in J-Box :-

Advantages :

i) J-Box offers economy in space, time, water, steam, and chemicals.

ii) Material to liquor ratio is 1:1. Minimum electrical power is required with advantage of variable speed.

iii) Uniform and reproducible absorbancy with good whiteness of the goods is obtained.

iv) Minimum handling damage with less loss of tensile strength is observed.

v) Fabrics of different width, weight and densities can be run through the plant without alteration or adjustment, except for speed and dwell time at each stage of the process.

Disadvantages :

i) J-Box system is economical only if the production target is big enough to feed the J-plant by about 2 lacs linear meter per day . However, smaller units have also been developed for handling 2 to 3 tons of cloth per day.

ii) Pin holes-catalytic action of iron coming from steam pipes is observed sometimes on the bleached fabric.

iii) Some silicates from the wet cloth containing bleaching solution may be deposited on the heated walls of the J-Box. The cloth sliding down the J-Box rubs against these silicate scales that lead to abrasion marks which shows up in subsequent dyeing.

iv) Due to great weight of the cloth, the lower portion of the fabric is subjected to great pressure, which may be up to 2 tons in larger J-Boxes. This may lead to severe rope marks in certain compact and heavier varieties of cloth. Continuous treatments in rope form are also likely to cause lengthwise crease marks.

7.5 Continuous Open-Width Bleaching Equipment

Some fabrics such as heavy drill, corded fabrics, satins and other sensitive weaves are liable to be damaged if they are bleached in rope form. Creaseless running and low cloth tension are also important factors for blends with synthetics. These necessitated the development of new types of open-width bleaching machineries for fabrics. Generally, a continuous open-width bleaching range consists of 2 to 3 units with maximum speed of 100 to150 m/min and reaction time of about 2-7 min per treatment unit. Different types of steamers can be combined in various ways to form a large number of different ranges, to cater for a broad spectrum of requirements in terms of productivity, fabric qualities and subsequent treatment [17,18]. It is difficult to explain various fabric paths in different types of steamers and steaming operations, however Table 7.4 mentions some of them.

For chemical pre-treatment of woven cotton and polyester/cotton blended fabrics Benninger has developed the ''Ben Bleach system'' for desizing, scouring and bleaching in one operation i.e, ''Ben-Injecta'' for desizing, ''Ben-Impacta'' for impregnation , ''Ben-steam'' for steaming and ''Ben-Extracta'' for washing. Following desizing in the ''Ben-Injecta/Ben-Extracta'' section, the fabric is saturated and loaded with bleaching solutions in the ''Ben-Impacta'' for high degree of penetration and high fabric -liquor interchange. Ben-Impacta (Fig. 7-18) is in its geometry like an upside down Injecta. The fabric passes through two long narrow slots , in

TABLE 7.4
Different Open-Width Continuous Bleaching Steamers [19]

Manufacturer	Name	Features
Artos	Continuous open-width steaming machines with ARTOX "Rapid Relax" U-box	(a) Capacity-400 kg/m of fabric width. (b) Running speed up to 100m/min.
Air Industry	Roll-a-Belt combination steamer	(a) Tight-strand section-30 m. (b) Conveyer capacity-100 kg of fabric per meter of width.
Brugmann Estafette	Conveyer steamer	Capacity-3000 m.
Benninger	Type DS combination steamer	(a) Tight-strand section 50,100 or 150 m. (b) Roller-bed-Minimum 7 min dwell at up to 150 m/min.
Goller	Conveyer steamer	(a) Capacity-300 to 400 m fabric per meter of conveyer. (b) A range of conveyer length is available.
Kleinewefer	Combi-steamer box	(a) Tight-strand section 40 or 80 m. (b) Roller-bed-400 to 600 kg of fabric per meter of fabric width. (c) Reaction time – 10 to 15 min.
Mather & Platt	Vaporloc Roller-bed pressure steamer	(a) Dwell time – 2 to 3 min at 100 m/min. (b) Pressure – up to 30 p.s.i. (c) Temperature – up to 134°C.

which the impregnating liquor circulates. Impregnation at 40°C is normal with perox-

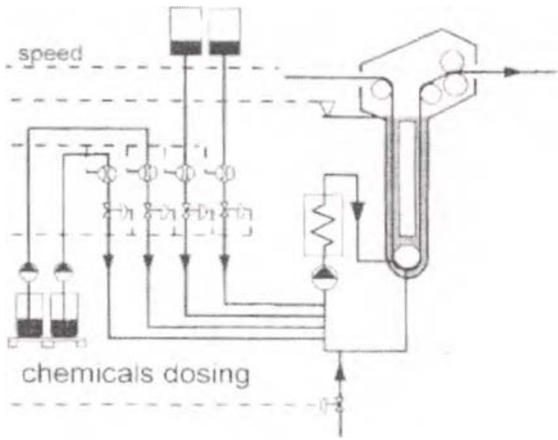


Figure 7-18. Impregnating unit (Ben-Impacta) for pre-treatment (Courtesy of Benninger AG).

ide, but with good stabiliser the temperature can be raised even up to 60°C. The advantages of this type of impregnating unit are : small liquor volume, intensive fabric-liquor interchange over a long reaction zone, variable liquor application, low consumption of chemicals, even saturation and loading, small space requirement, no streakiness or creases and self- regulation of liquor concentration. Monitering of the liquor concentration in the impregnation unit is nonessential, except at material changeover.

7.5.1 Steamers without plaited storage

Figures 7-19 to 7-23 show the various fabric paths in continuous open-width bleaching equipment with steamer systems based on positive fabric guidence without plaited storage. The main features of this system are : very much suitable for crease susceptible fabric, fair degree of whiteness, fabric with good absorbancy, less chances of fabric degradation and fair mote removal.

7.5.2 Conveyer steamer without pre-steeping zone

Conveyer steamer was first designed by Mathieson Alkali Corporation in USA [20]. Figs. 7-24 to 7-28 show the line diagrams of such conveyer steamer systems based on plaited fabric storage without pre-steeping zone. During the early 60s steamers were developed to treat the cloth in open-width form for very short steaming time (90-120 secs) at 120-130°C under pressure for continuous scouring

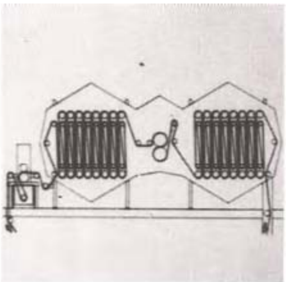


Fig. 7-19

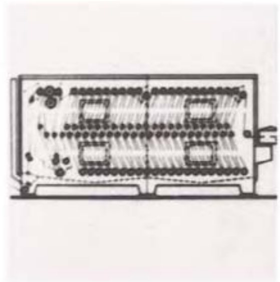


Fig. 7-20

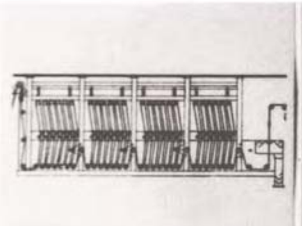


Fig. 7-21

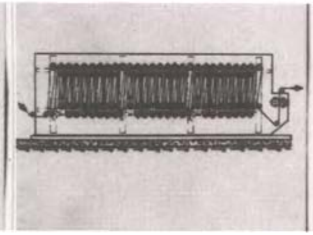


Fig. 7-22

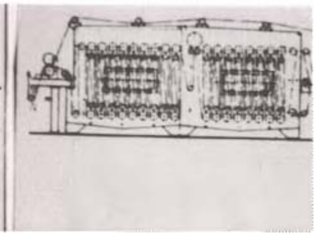


Fig. 7-23

Figures 7-19 to 7-23. Steamers without plaited storage. Figure 7-19. Babcock KG ; Figure 7-20. Benninger AG ; Figure 7-21. Klieinewefers GmbH ; Figure 7-22. E. Kusters ; Figure 7-23. Omez S.p.A.

and peroxide bleaching [21]. The main difference between the Kleinewefers (Pressurlok) and Mather & Platt (Vaporloc) systems is the means of fabric transport. Klienewefers uses a tight-strand design while Mather & Platt uses a roller-bed system. The latter allow greater flexibility in running speed [22]. The rollers are positively driven which pushes the fabric forward. The time for storage varies from 7 to 15 min or more. The entire set of rollers is placed in a steaming chamber. The fabric content is about 6000 m at a production speed of about 100 m/min. The fabric is sensitive to creasing owing to the tightly compressed cloth piles within the steamer. Tight-strand steamers with a reaction time of 1 to 2 min and without any plaiting or batching avoid above difficulties. Howerer, these units are not suitable for fabric containing seed husks which are, even otherwise difficult to remove [23].

In the multilayer conveyer steamer (Fig. 7-29) the cloth is bleached by

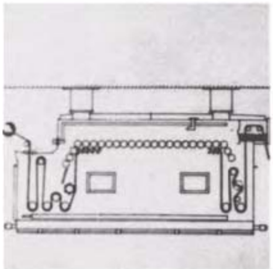


Fig. 7-24

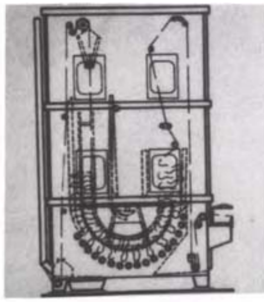


Fig. 7-25

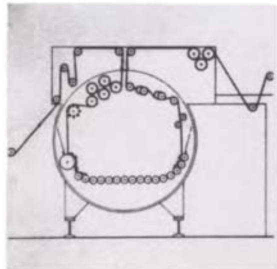


Fig. 7-26

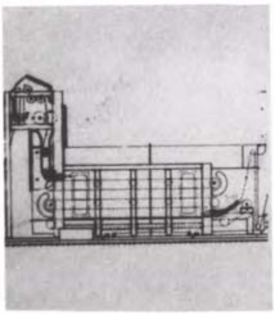


Fig. 7-27

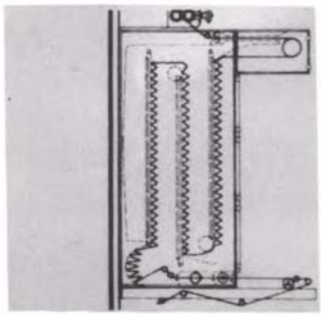


Fig. 7-28

Figures 7-24 to 7-28. Steamers with plaited fabric storage without pre-steeping zone. Figure 7-24. Babcock KG ; Figure 7-25. Sir James Farmer Norton ; Figure 7-26. Kleinewefers GmbH ; Figure 7-27. Mather & Platt Ltd ; Figure 7-28. K. Menzel.

impregnating with peroxide solution, and then drawn into a steamer where it is plaited on to a slowly moving conveyer by the action of steam jets. The time of steaming can be varied by altering the speed of the conveyer. Speeds of 60 to 100 yds/min are claimed. The fabric is then withdrawn from the conveyer at the exit end of the steamer and washed in an open soaping range.

7.5.3 Conveyer steamer with pre-steeping zone

The various fabric paths in continuous open-width bleaching equipment with a conveyer system based on plaited fabric storage with pre-steeping zone are outlined in Figs. 7-30 to 7-33. The salient features of this system are : not much suit-

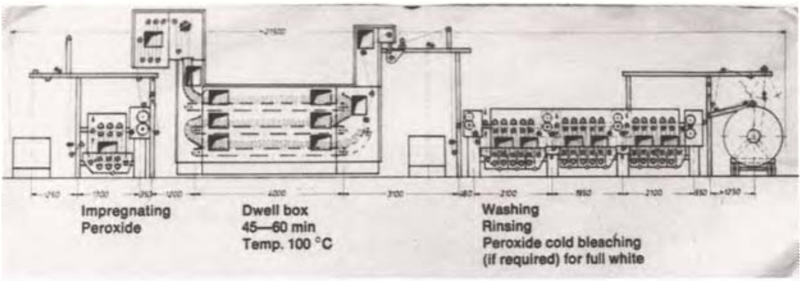


Figure 7-29. Continuous open width bleaching range (Courtesy of Maschinenfabrik Max Goller).

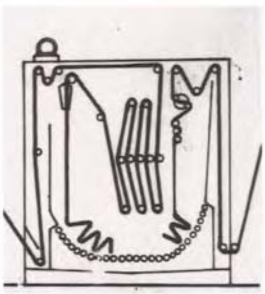


Fig. 7-30

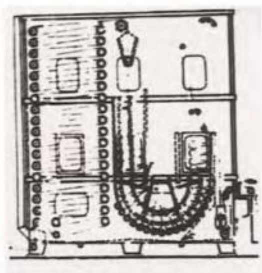


Fig. 7-31

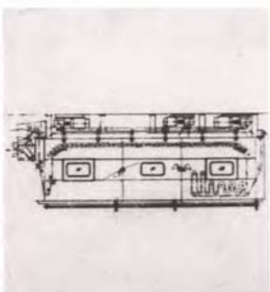


Fig. 7-32

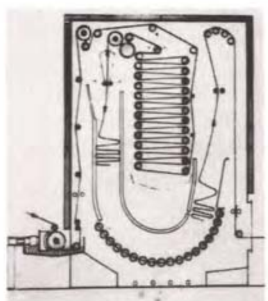


Fig. 7-33

Figures 7-30 to 7-33. Conveyer steamers with pre-steeping zone. Figure 7-30. Babcock KG ; Figure 7-31. Sir James Farmer Norton ; Figure 7-32. Kleinewefers GmbH ; Figure 7-33. Mather & Platt Ltd.

able for crease sensitive fabrics, fair degree of whiteness, better absorbancy, low DP values and fair seed husk removal. Such steamers also have tight-strand section of 40-80 m with a roller-bed of about 400-600 kg of fabric per meter of fabric width with a reaction time of 10 to 15 minutes.

7.5.4 Pressureless or combi-steamers

The combi-steamers are associated with horizontally laid out positively driven roller-bed and a heating-up and reaction zone which is judiciously combined. The tight-strand fabric transport has the object of ensuring uniform swelling of cellulosic fibres. Here the fabric is subjected to lengthwise tension and the rollers simultaneously exert an ironing effect which levels out internal tension within the fabric during the treatment. The plaiting down system on the conveyer belt or roller-bed offers flexibility as far as the reaction times are concerned, and allows production speeds up to 150 m/min. Some typical combination steamers are shown in Figs. 7-34 to 7-37. One-step continuous bleaching range with maximum impregna-

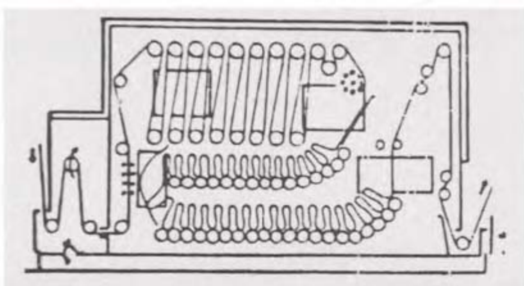


Figure 7-34. Benninger type DR combination steamer.

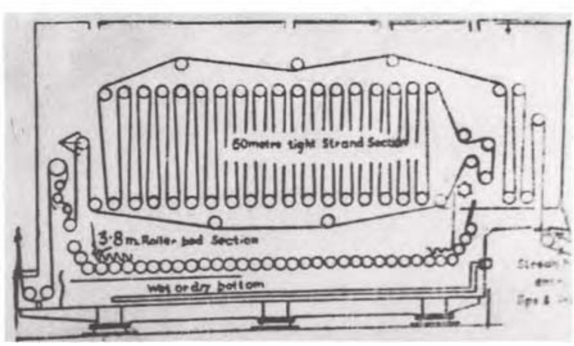


Figure 7-35. Farmer Norton combination steamer.

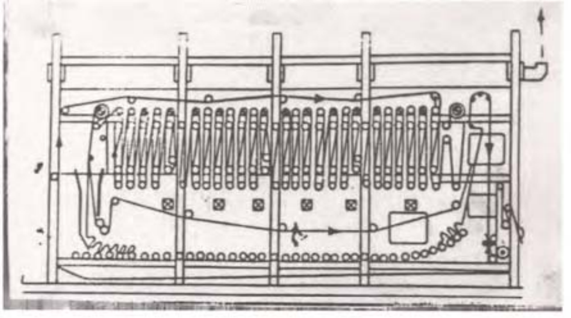


Figure 7-36. Kleinewefers combination steamer.

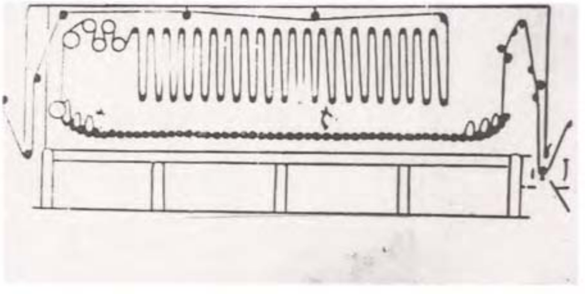


Figure 7-37. Mather & Platt combination steamer.

tion using combi-steamer is shown in Fig. 7-38. The first step of the unit for maxi-

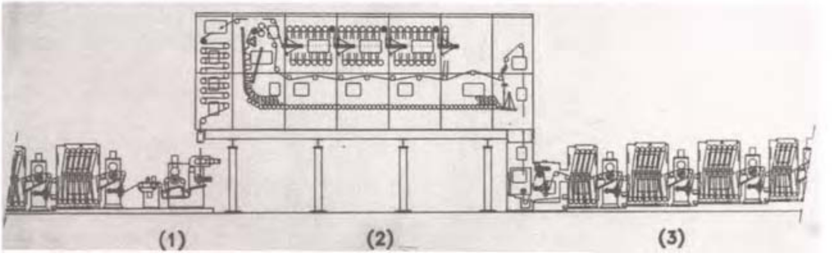


Figure 7-38. One-step continuous bleaching range using combi-steamer (Courtesy of Exclusivas TEPA S.A.).

mum impregnation (1) is a combination of spraying and vacuum extraction by which the fabric attains a previous residual moisture of 35-55%. The fabric is then passed through Pad-Steam bleaching steamer, ''combi'' type (2) with upper fabric passage between rollers and lower roller-bed for long batching. The washing units (3) at the end of the steamer completes the range.

In all types of combi-steamers the fabric enters through an air-lock which is followed by heating-up zone at 100°C for about 15-20 min. From the extreme end of the steamer the fabric is carefully led out of the machine through the delivery air-lock. The tight-strand steamer section of the combi-steamer is assembled on a modular principle. Each module generally has a fabric content of 50 meters. The problem of crease marking is also eliminated in all types of fabrics.

7.5.5 Continuous submerged bleaching system

The continuous submerged bleaching process is also known under the designation PKS (peroxide continuous rapid bleach) process [24]. The horizontal storage chamber and the continuous PKS range are shown in Figs. 7-39 and 7-40 respectively.

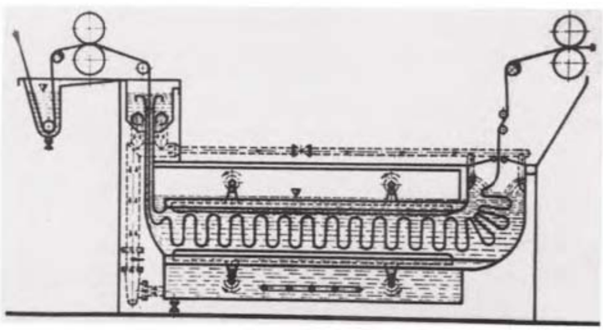


Figure 7-39. The horizontal PKS storage chamber.

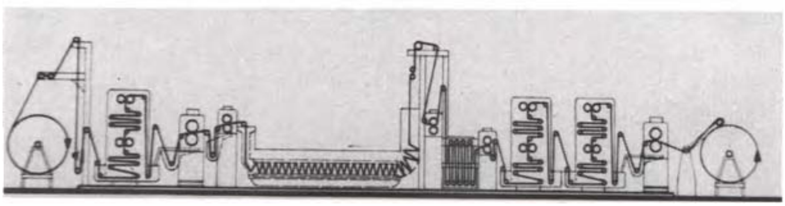


Figure 7-40. Continuous, submerged, open-width PKS range.

Ahead of the store (Fig. 7-39) is an impregnating padder to apply various liquors required. After padding, the fabric is run over a guide roller into the entry slot and passes through a hot aqueous bleach liquor which allows bleaching for 15-20 min at 95-98°C. The liquor which is continuously circulating and overflowing in the pre-chamber, sweeps the fabric gently and without tension into the horizontal storage chamber, which is closed at top and bottom by a special conveyer grid that is driven by means of cam-shaft. At each revolution of the shaft the fabric, which is plaited down in folds, advances a given distance. This conveyer grid is fitted above and below the storage chamber to enable all kinds of goods to be treated. Part of the circulated liquor is fed to the goods running out so as to prevent creases owing to over-rapid cooling in the plaited state. Because the dwell occurs under the bleach liquor surface, the process is also referred to as ''under liquor bleach''. Bayer followed their original reports with others [25-28]. A recipe for reservior is given in Table 7.5 and the economy of the process is reviewed [29].

TABLE 7.5
PKS Bleaching Recipes from Bayer and Menzel [30]

Chemical	Bayer	Menzel
Organic stabiliser (g/l)	6	5
Sodium silicate, 79°Tw (g/l)	7	6
Wetting agent (g/l)	–	1
Detergent (g/l)	2	1
Sodium hydroxide (solid, g/l)	4	4
H_2O_2, 35% (ml/l)	20	10-17
Minimum dwell time (min)	10-15	20-40
Temperature (°C)	95	85

The fabric leaves the store via a regulator and a pair of squeeze rollers, then runs to a wash unit and bleaching can be made into a continuous process (Fig. 7-40). The use of tower washing units, which work according to a pure counter current principle can save water during washing. Küsters [28] additionally recommended a steaming stage for the fabric emerging from the reservior, before washing and drying. In 1986, Heetjans [31] and Witte [32] announced the entry of Thies into the PKS market. It is claimed to produce 400-500 kg/h at a running speed of 40 m/min.

This machine is very good for the bleaching of all types of woven and knitted fabrics of natural and synthetic fibres and their blends, as well as for the bleaching of coloured woven goods as very little tension is applied. Advantages claimed for this process are : minimum chemical damage, short bleaching time at an average liquor ratio of 15 : 1, low machinery costs and good shrinkage values. The main disadvantage is the bleaching chemical cost.

7.6 Washing Equipment

Washing is called for at all stages of textile processing, in pre-treatment, after dyeing and printing, after resin finishing etc. The aim is to remove impurities, size, softening agents, lye, degradation product, residues of auxiliaries, unfixed dye, thickening agents used in printing etc. All these substances must be water soluble or, with the aid of added chemicals, emulsifiable. Fig. 7-41 shows the situation

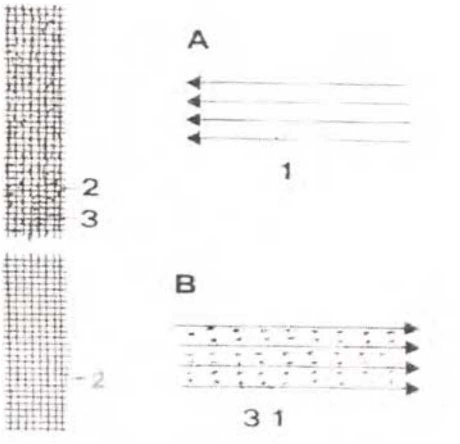


Figure 7-41. Situation before and after washing [32].
A – Actual state ; B – Desired state ;
1 – Liquor, 2 – Fabric, 3 – Extraneous matter.

before and after washing. In general the washing process can be divided into three phases : loosening of extraneous matter, transfer of extraneous matter and removal of extraneous matter. In the first phase the extraneous matter must swell and loosen as quickly as possible. In the second phase the matter is transported by diffusion to the layer of liquor flowing next to the surface of the textiles. In the third phase the extraneous matter is carried away by the flow of the washing liquor and the movement of the goods. In actual practice all the three phases are found to overlap. Washing is characterised by maximum efficiency combined with significant savings in water, electricity, heat and chemicals. The efficiency of washing action is promoted by mechanical movement, liquor flowing counter to the run of the goods, efficient drives and controls, suitable fabric guides etc. Taking all factors into consideration, the best average consumption for modern machines is of the order of about 4-6 kg water/kg goods.

The fabric can be washed in rope and open-width form. Pot eyes, made of porcelain or stainless steel, are used for drawing the fabric in the rope form from one step to the other. Open-width washing gives more uniform results than does the rope form. Furthermore, delicate fabric and texturised woven and knitted fabrics need a very soft treatment during scouring and washing. Both the form, that is the rope and open-width washing can be done in batchwise or continuous fashion. Manufacturers all over the world have marketed and established their rope and open-width washing machineries and it is difficult to describe all of them, however, a few of them designed on different principles are described.

7.6.1 Rope washing machines

The line diagram of tight rope washing machine is given in Fig. 7-42. The machine

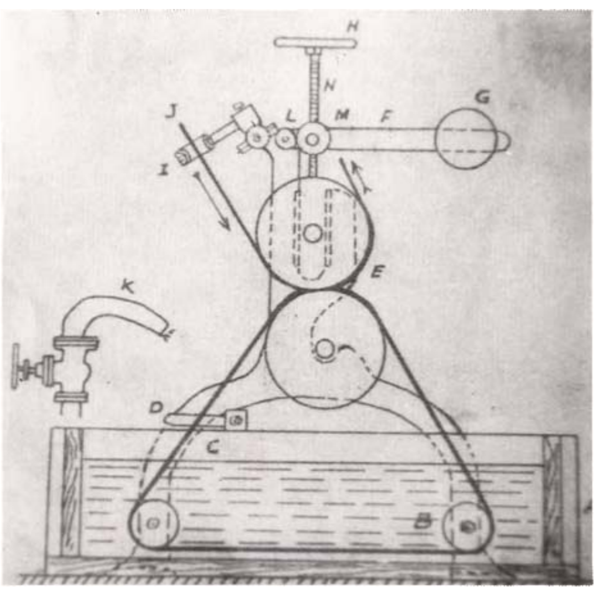


Figure 7-42. Tight rope washing machine.

consists of two cast iron side frames and a pair of heavy and wide squeezing bowls (E). The bowl is driven positively while the upper one rotates by frictional grippage. Two ropes of cloth are generally washed at a time. One rope (J) enters through a pot eye (I), passes into the nip of the squeezing bowls (E), enters the water in the trough (A), passes under the trough guide rollers (B) and between the pegs (D) and then passes into the nip again. Pressure is applied by simple lever (F) and weight (G). H is the handwheel, L is fulcrum, M is internally threaded block and N is threaded bar. The passage of both the ropes through the machine continues in a spiral fashion to the centre where both the ropes finally leave the machine. The tank usually receives fresh water (K). The out put of the machine is about 250 to 350 m/min. Due to considerable tension on the fabric, this type of machine is utilised in the case of medium or heavy fabrics.

In the slack rope washing machine (Fig. 7-43), the fabric rope is allowed to drop

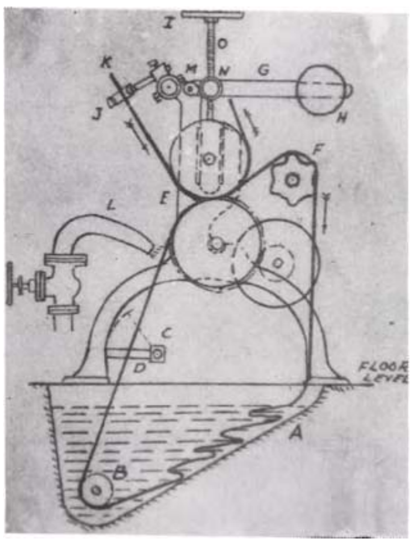


Figure 7-43. Slack rope washing machine.

down the machine tank and is maintained there for a certain amount of time in a relaxed form. The fabric rope (K) enters the pot eye (I), passes between the squeezing bowls (E), over the winch (F) and then into the deep trough (A) with a sloping base down which the cloth falls in a slack and slightly plaited state. The fabric then passes under a wooden guide roller (B), then upward between the pegs (D). A peg rail (C) is fitted to prevent the entanglement of ropes and then passes through the nip again. Thus, the fabric takes a spiral path. The production is about 150 m/min with an water consumption of about 6 to 8 litres/kg of cloth.

Another type, namely square beater washing machine is used mainly for washing printed goods. The beater revolves in a direction opposite to that of the cloth so that it receives a flapping motion which beats out loose particles adhering to the fabric.

The high speed rope washing machine (Fig. 7-44) offers efficient processing

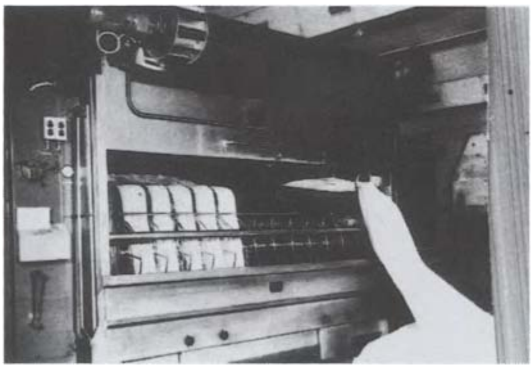


Figure 7-44. High speed rope washer (Courtesy of Hemmer, Germany).

without cumbersome threading up. In this type the liquor trough is divided into two or more parts or sections by means of clearly rounded removable partitions. The fabric is fed into the machine from a suitably positioned pot eye and first washed in one side of the partition and then on the other side and so on. The wash liquor is arranged to flow in a direction opposite to the fabric rope. The fabric rope passes alternatively under a stainless steel bottom roller and a loose stainless steel bobbins on the top shaft. At the end of the washing section, the fabric passes through pneumatically loaded squeeze device located at the top. The machine is totally enclosed and fitted with sliding glass panels. The fabric is guided through the machine in such a manner that lowest possible tension is exerted on the fabric. The high performance rope washing machines may be employed both as a single unit or in continuous operation with similar machine with a working speed of up to 200 to 250 m/min.

After rope washing, the fabric is passed through the rope squeezing machine

(Fig. 7-45) which allows the fabric to have reasonably consistant water content.

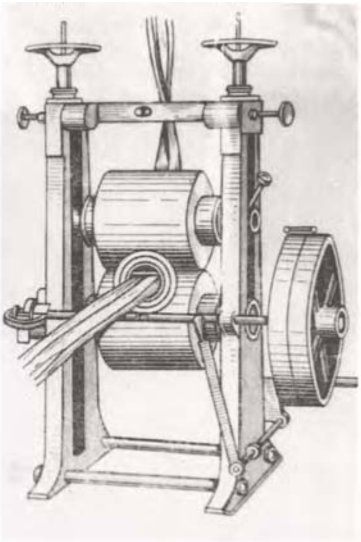


Figure 7-45. Rope squeezing machine.

The fabric is then piled uniformly in the storage pits or glazed tile lined piling pits. The bin pilers (Fig. 7-46) drop the fabric on pits. The pilers are mounted on rails

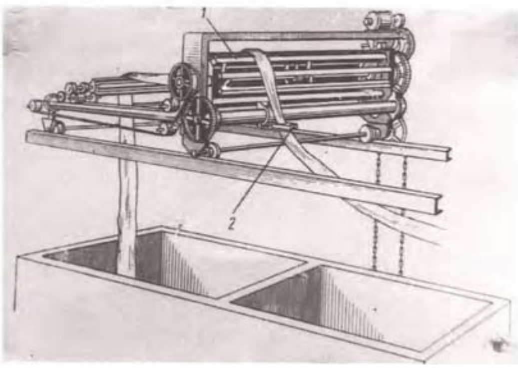


Figure 7-46. A carriage piler for fabrics.

which move forward or backward in one direction over the rope of pits. Then the fabric is opened out from rope to open width form with the help of an opener (Fig. 7-47) or scutcher (Fig. 7-48). Rope expanders or rope openers are usually fitted

Figure 7-47. Rope opening line for woven and knitted goods (Courtesy of Bianco, Italy).

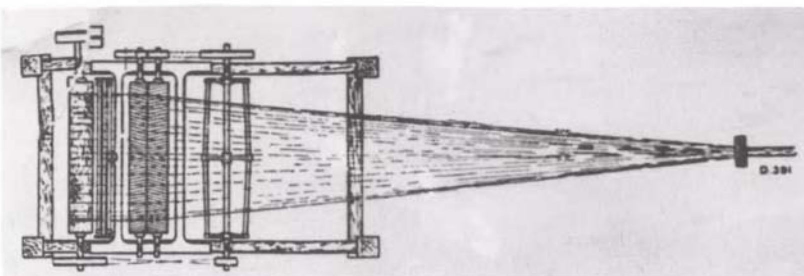


Figure 7-48. Diagram of scutcher for opening cloth from rope form.

behind the rope washing machines. In the case of rope openers without scutcher, the fabric ropes are opened with the aid of cloth guiders and sometimes additional scroll rollers are used. The scutcher usually consists of a revolving brass beater, two scroll rollers, a pivoted guiding device and draw rollers. The two scroll rollers are geared together by means of spur wheels and are driven in pairs in the counter direction to the cloth which passes between them. The beater is also driven in the opposite direction of the cloth. For both the systems, an adequate unhindered feeding distance of at least 6-8 m is necessary to ensure that the fabric rope can be sufficiently detwisted. Occasionally rope detwisters are fitted between the last rope guide ring or wheel and the rope opener. Scanners sense the direction of twist of the rope and appropriate signal is given to the controll element. Sometimes "Whittler" rope openers are fitted with the scutcher and the particularly good opening effect is due to the fact that the fabric rope is subjected to a rhythmical undulating movement of the two, three, or four part scutcher, which causes the rope to loosen up and decrease, and existing twist is eliminated. The essence of the "Whittler" rope opener is, however, the regulator (Fig. 7-49), which keeps the open-width fabric on centre

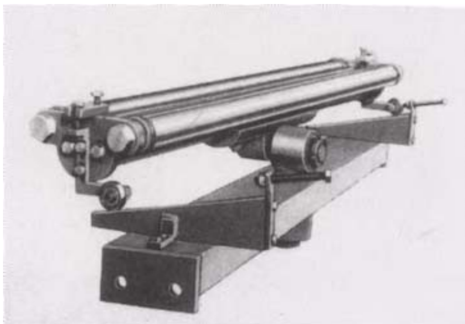


Figure 7-49. Whittler rope opener regulato...

and guides it to further processing operations. Machine speeds from 120-180 m/min can be achieved if the regulator can fulfil its task in every respect. With rope openers of other designs machine speeds of only 40-60 m/min can be attained.

After leaving the opener, the cloth is then passed through hot water in water

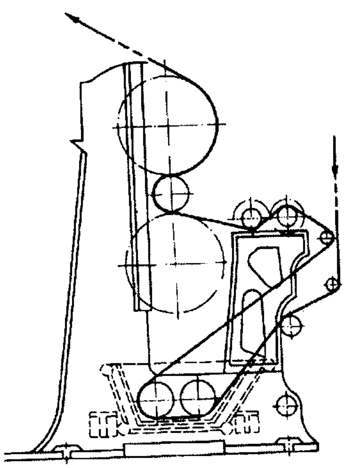


Figure 7-50. Water mangle.

mangle (Fig. 7-50). The water mangle removes last traces of dirt, excess water, rope marks and flattens the fabric. A water mangle has 3 to 6 bowls, but sometimes even 8. The mangle is equipped with an entry scaffold, an adjustable tensioner, two scroll rolls and automatic cloth guiders suitable for wet fabrics at the entry side and a piling winch at the delivery side. The cloth speed ranges from 100 to 200 m/min depending upon the type of the fabric. The water mangle can be synchronised with the dryer, which usually follows the water mangling process.

7.6.2 Open-width washing machines

Of the many open-width washing machine concepts, the three drum washing machines, namely perforated oscillating drums, perforated drums with oscillating central units (Rotowa), perforated rotating drums and spraying arrangements are very popular in the batch form. The more common type of open-width continuous washing machine is open soaper. Modification followed modification in which the manual operations are progressively mechanised, the aim being to co-ordinate the individual steps. Different effective and inexpensive systems for washing even very sensitive woven and knited goods are available.

In the suction drum washing machine (Fig. 7-51) the scouring liquor is drawn

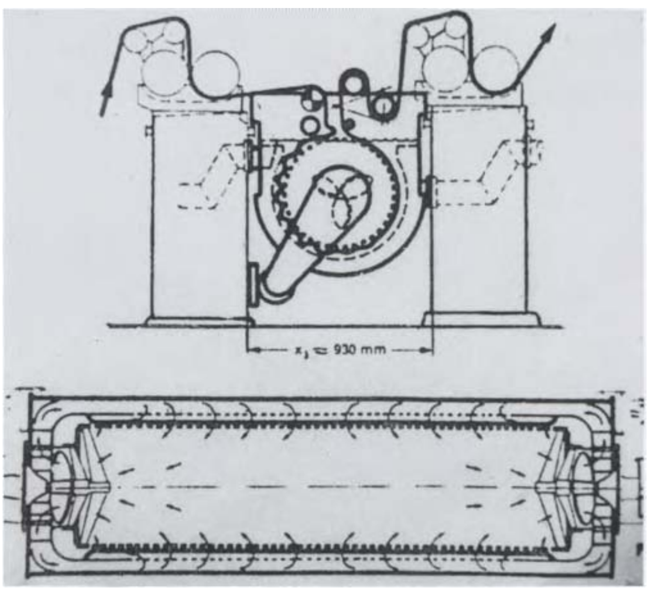


Figure 7-51. Suction drum washer (Courtesy of Artos, Germany).

through the perforations of the drums, and the fabric interstices, thus effectively removing the water soluble material. Suction drum washers usually have two or more bowls driven at some synchronous speed, the fabric covering about 80% of

Fig. 7-52.

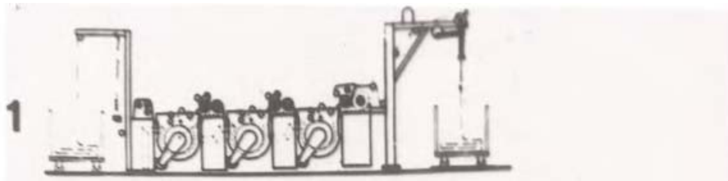


Fig. 7-53.

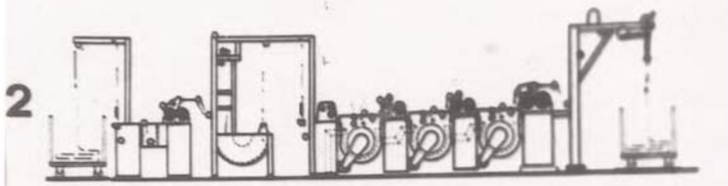


Fig. 7-54.

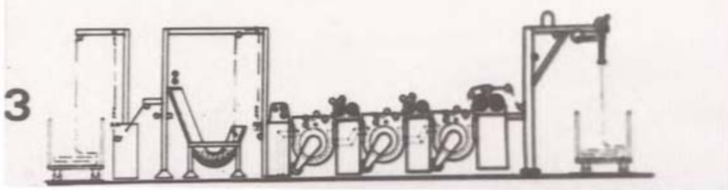


Fig. 7-55.

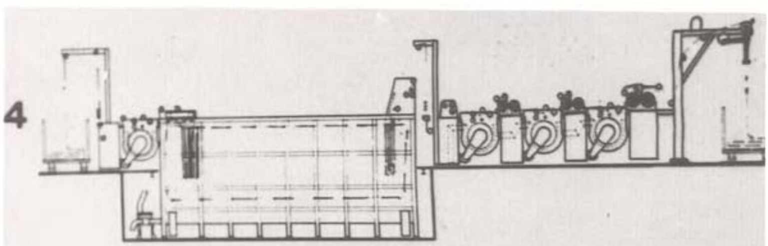


Fig. 7-56.

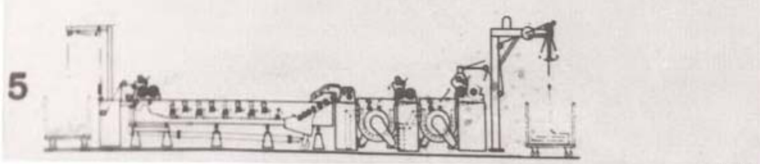


Figure 7-52 to 7-56. Typical installations of various suction drum washing ranges [32].

the circumference of the drums. Liquor is pumped out at the end of the drum (Fig. 7-51) and is recirculated through the washer. Edge uncurlers are fitted before the first drum on the machine. A simple nip may be fitted between the successive bowls. The function of the nip is mainly to advance the fabric into the unit rather than to remove the surplus liquor. The suction drum washing machine (Fig. 7-52) treats the goods under low tension with a good convective rinsing action. The same machine can be used in tendem with impregnation squeeze rollers (Fig. 7-53), with impregnation trough (Fig. 7-54), with festoon boiling off range followed by rinsing tanks (Fig. 7-55), and special washing and bulking machine followed by rinsing tanks (Fig. 7-56).

In the Rotowa washing machine (Fig. 7-57) the fabric is wound on to the perfo-

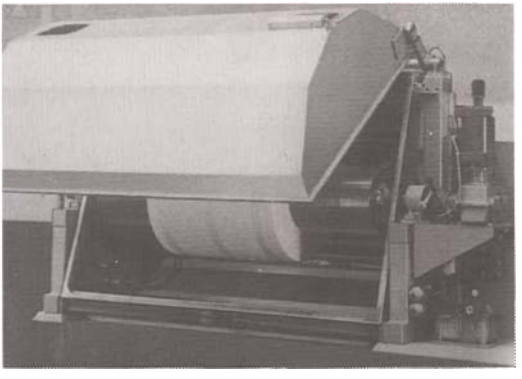
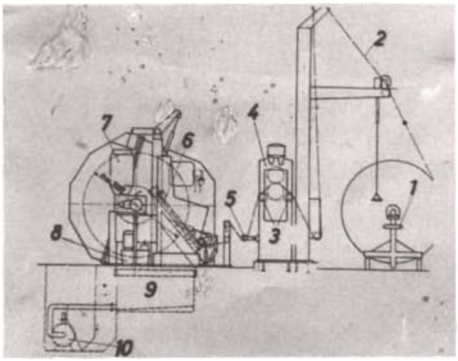


Figure 7-57. Rotowa washing machine (Courtesy of Heberlein & Co. AG).

rated beam on the batching trolly. The range (Fig. 7-58) comprises with perforated drum and liquor circulation, plus associated combined winding and washing drive. The fabric is washed by pumping liquor through the perforated drum. The liquid is forced from the centre to the outer layer of the fabric batch at right angles ensuring good washing effect. This process is intensified by the centrifugal action of the drum. Working speeds range from 20 to 140 m/min. The range is supplied in roller widths of 1400 to 3600 mm. The water consumption is 6-8 l/kg of dry goods. On completion of processing, the chamber is opened and the goods are reversed through the squeezer or feed rolls and either wound up onto a giant batch or plaited down.



1. Batching unit
2. Fabric
3. Expander rollers
4. Squeezer with d-c motor
5. Faller roller
6. Winding arm
7. d-c motor winding and washing drive
8. Hydraulic system
9. Liquor reserve
10. Circulation pump

Figure 7-58. Rotowa open width washing range (Courtesy of Heberlein & Co. AG).

The spray drum washing machine (Fig. 7-59) consists of stainless steel perforated drum which allows easy wash liquor through the perforations. The drum runs in ball bearings mounted outside the tank. The movement of the drum is brought about by the drag of the running fabric. The washing drum is set in a stainless steel tank, with provision to properly drain away the wash water. A set of nozzle batteries is placed round the circumference of the drum, with a view to spray water jets on the fabric. The jet washer (Fig. 7-60) consists of a trough and a cascade zone.

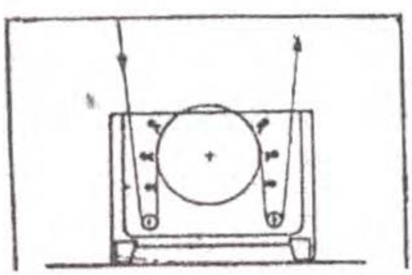


Figure 7-59. Wash tank with spray drum.

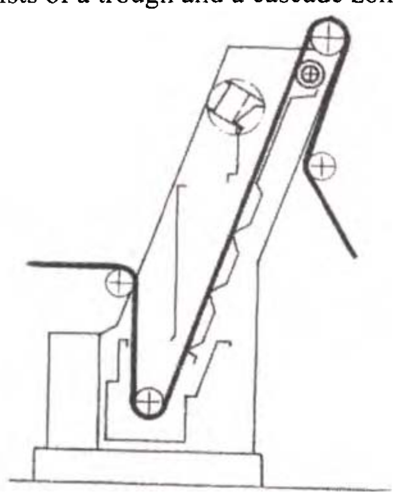


Figure 7-60. Jet washer (Courtesy of E. Küsters, Germany).

Above the cascade zone, there is a nozzle with a wide slot which forms a continuous curtain of water across the full width of the goods. The trough is fitted with filter and liquor circulation pump. Water is pumped into the fabric at a high speed via the wide slot nozzle. The cascade zone, an inclined plane, ensures that the water from the wide slot nozzle has to flow through, and in countercurrent with, the pile. The fabric runs over the drum and is guided to be taken away from the drum over suitably positioned, ebonite covered, rollers running in ball bearings.

In some cases a longer washing time with spray is required and this can be achieved by using wash tank containing roller bed as shown in Fig. 7-61. The fab-

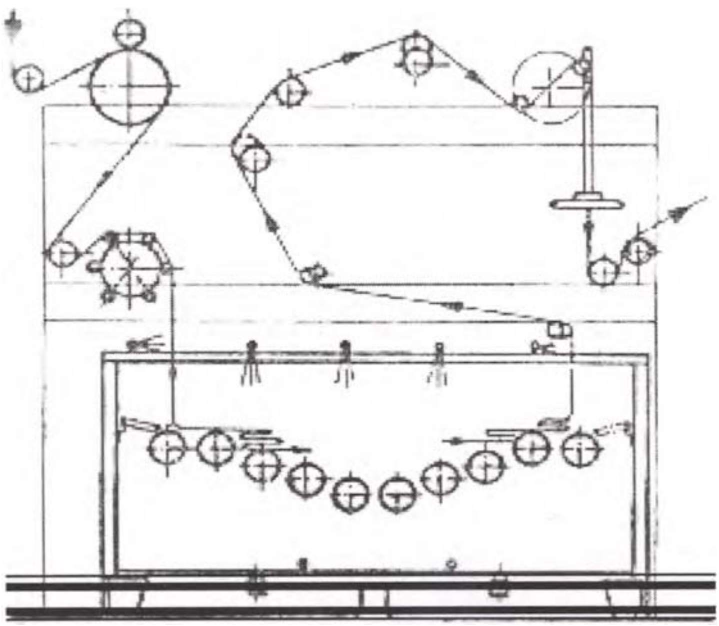


Figure 7-61. Spray washing and soak tank roller-conveyer.

ric transport is effected by means of a positively driven set of transport rollers. The first roller pushes the cloth, the second roller in turn transport the fabric to the third roller and so on. About 150 to 300 m of fabric is piled on the roller conveyer in order to allow complete relaxation of the fabric. A powerful spray through the jet is arranged for an efficient washing of the fabric, while the fabric is adequately soaked in the roller bed. The fabric is lifted and led further from the washing part over a set of guide rollers and a special rotary fabric guiding device.

The open soaper is the common type of continuous washing machine in open-width form (Fig. 7-62). The machine consists of six or more compartments or

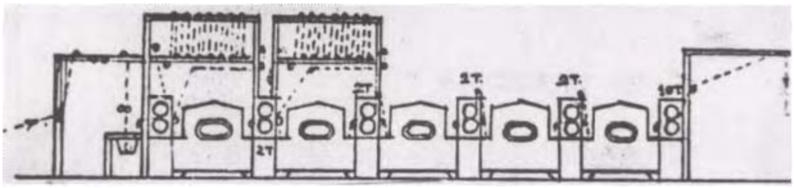


Figure 7-62. Continuous open-width washing range (Courtesy of Farmer Norton, Type R-16).

tanks depending upon the processes to be carried out. It has a series of bottom and top rollers. The lower set is usually immersed in the washing liquor. The fabric passes over the adjustable tensioners and then over and under the guide rollers which guide the fabric in vertical folds through different liquors in the tank. The fabric is sprayed with water from the spurt pipes and squeezed between the bowls before entering the next tank. The speed range of this machine varies between 20-40 m/min depending on the number of tanks. The execution of the machine may be open at the top or closed depending upon the expected performance of the machine. In some machines the washing tanks are fitted with special beaters (Fig. 7-63) to have more efficient washing. The beater consists of copper gutters

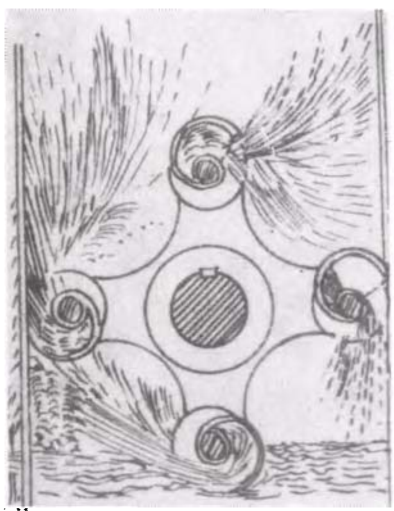


Figure 7-63. Beater with four swivelling gutters for washing tanks.

soldered on stiff steel rods, the ends of which are carried loose on spider wheels keyed on beater shaft. Two sets each of three beaters are inserted between the folds of the cloth and do not touch the fabric. The beater revolves at a great speed, so that gutters are caused by the centrifugal force to fly out. They are partially dipped into the water and give an elastic beating without rubbing. For soaping and washing of delicate goods with a minimum tension, Aquatex soaper (Fig. 7-64) with expres-

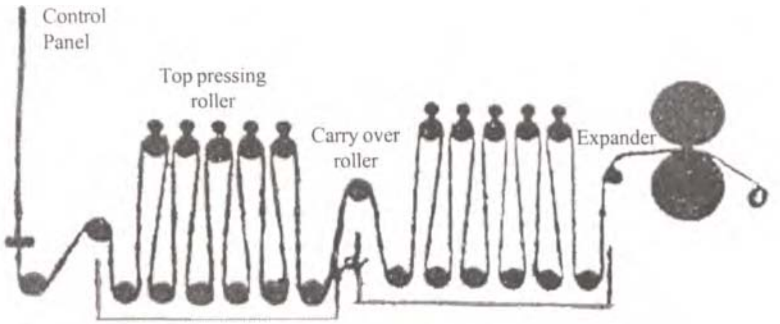


Figure 7-64.Aquatex units with expression nip.

sion nip is used. In this modified machine, every roller runs on ball bearings. The top rollers are driven by roller chains or V-belts in a bank of five or six, which make-up the compartment or unit. The bottom rollers are freely rotating in bearings which are sealed and self-lubricating. Both top and bottom rollers are 12 to 13 cm in diamerter. These arrangements keep the cloth under controlled tension throughout. Another modification is the open soaper with double fabric threading (Fig. 7-65) which gives increased production, economy of space and capability of

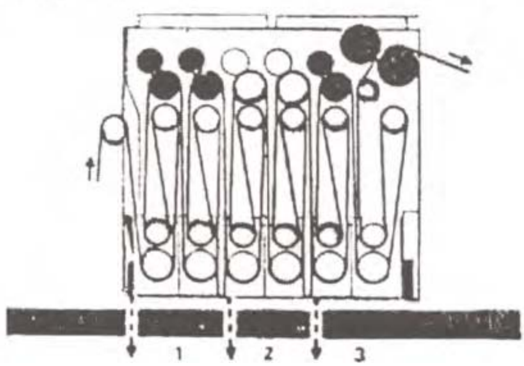


Figure 7-65. Benninger Becoflex washing compartment.

processing goods of any width. Creation of turbulance in the wash tank by arranging ingeneous fabric passage forward and reverse is an added advantage. Such unit is also used to remove alkali from the mercerized cloth. However, this arrangement is more complicated and costly. The need to improve the washing efficiency has further led to the adoption of counter-current flow, of the wash liquor, in the washing compartment (Fig. 7-66). Vertical metal plates seperate the liquor between the

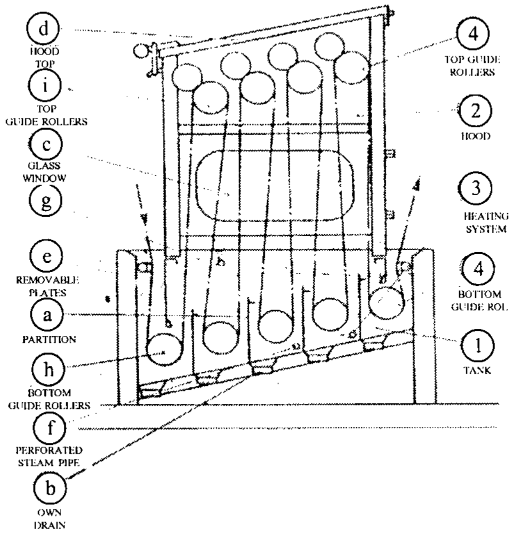


Figure 7-66. Counter-current open-width washing unit.

metal rollers. The liquor flows in the direction opposite to the fabric travel either by cascade arrangement of the sections or by arranging vertical positions in such a manner, that the liquor flows in a serpentine manner. Each seperate successive immersion of the fabric is in a cleaner liquor, whereas the liquor becomes increasingly contaminated as it approaches the discharge point, close to the fabric entrance. Similar arrangement is used for washing mercerized cloth in chain mercerizing machine.

Washing compartments with a horizontal fabric run have been purpose-built down to the very last detail. In horizontal fabric layer washing machine (Fig. 7-67), the fabric enters at the bottom and stepwise ascends to the top. The distance between the two vertical banks of rollers is about 70 cm. Washing is done by multiple counter-current principle. The fresh water enters at the top, and after being expressed at the top roller is collected in the tray and fed to lower ones, turn by turn. Intermediate squeezing of the fabric at the extreme positions increases the washing

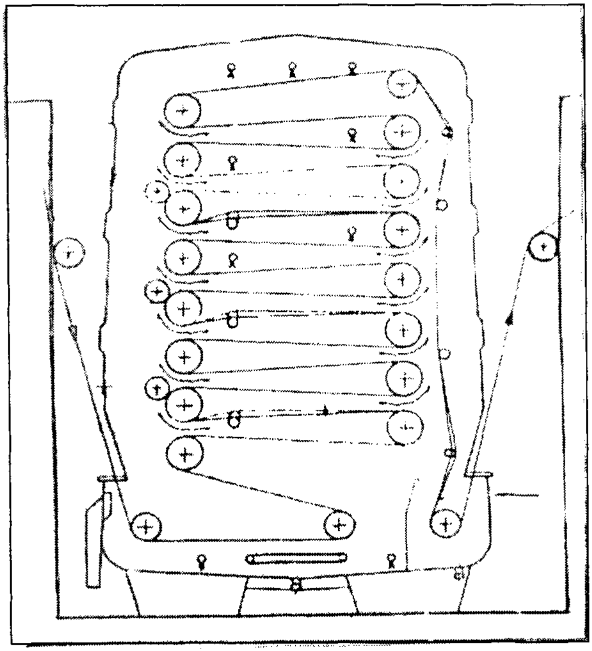


Figure 7-67. Horizontal washer.

efficiency. Each washing unit holds 24 m of cloth and fabric changes direction 12 times. The machine can be coupled together as duplex or triplex assembly. Water consumption is about 4 to 5 l/kg of fabric. The horizontal fabric run has fundamental advantages because of the automatic two-sided treatment, beneficial counter-current flow with liquor circulation, more efficient use of space, use of gravity, centrifugal force and guide roller washing action. Provided full use is made of the available height, horizontal fabric guidence enbles 2 washing compartments to be arranged one above the another. The top compartment can be run with fabric and liquor in counter-current, while in the bottom compartment the liquor is circulated. Using this arrangement, radial flow can be combined with the tangential flow along the fabric surface essential for washing, and diffusion can still take place.

The importance of squeeze rollers for liquor exchange on open-width washing ranges has been demonstrated by many machinery manufacturers. In one system the goods are squeezed off while hot to exploit the lower viscosity of water. Spray assembly to remove insoluble impurities from the fabric by sweeping away by kinetic energy is mentioned. High rates of hydroextraction are achieved by the

Roberto roller principle. ''Bicoflex'' roller produced by Kleinewefers-Jaeggli/of Germany is designed more for uniform expression : an air cushion inside the roller automatically adjusts the pressure to ensure an uniform squeezing effect, even with extremely narrow or thick goods. In the conventional sqeezing units pressure is applied pneumatically or hydraulically. However, in the ''Aquapress'' squeezing unit (Kusters) pressure is applied hydrostatically i.e. by means of a large diameter cylinder floating on the liquor. The nip is formed by this floating (stainless steel) roller and a driven counter-roller. It provides even line pressure over the full width of the nip. The roller surfaces are self-cleaning in this system.

The degree of expression largely determines the cost of drying afterwards. Fig. 7-68 shows a few conventional hydroextraction systems. The floating roller

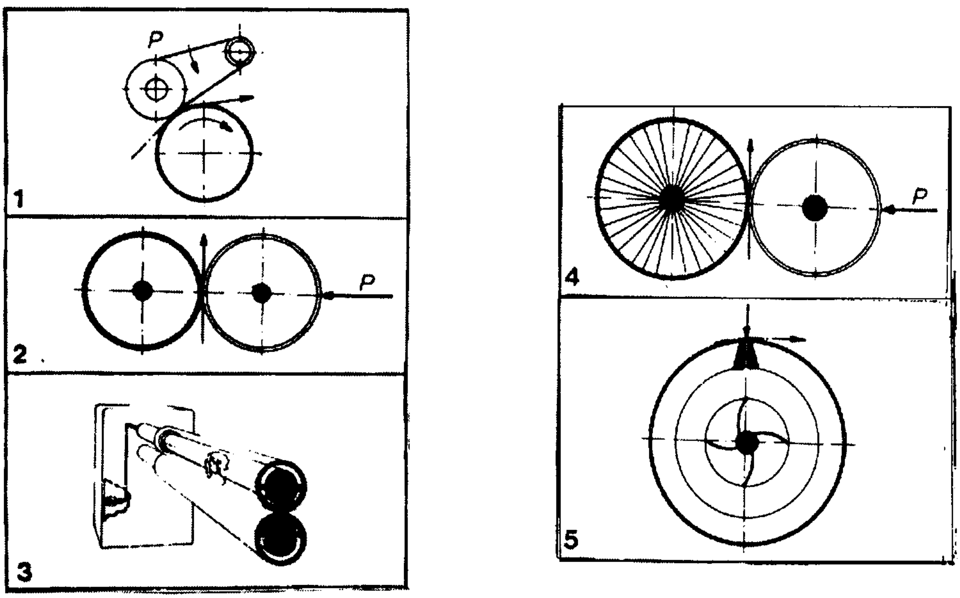


Figure 7-68. Different types of hydroextractor.
1. Feed roller, 2. Horizontal nip, 3. Floating roller,
4. Roberto squeeze roller, 5. Suction device, P Force.

arrangement has already become a tradition. Good results are achieved with suction or other squeezing systems. Suction systems are heavy consumers of energy. Chemical finishes have traditionally been applied to the fabrics using immersion (dip padding) or low wet pick-up techniques such as lick roll, porous bowls, vacuum extraction or foam [33]. Alternative methods include coating and laminaiton technologies [34]. In the Nextec Application process [35] individual fibres within the fabric are encapsulated or wrapped with an ultra-thin film of polymer. A specially designed blades are used to shear thin polymer compositions into fabrics that are under tension. Pre-treatment of the fabric, and polymer selection are used to increase the polymer flow and prevent saturation of the fibres. On removal of the shear forces, the polymer return to a higher viscosity and then the polymer is cured. It is, thus, possible to provide breathable barrier film as low as 100 nanometers and up to several microns within the fabric, preventing liquid water from penetrating while allowing moisture vapour to pass through to close to the same rate as the original fabirc. This technique of fibre encapsulation process is already being applied on silicone-based polymers, polyurethanes, polyacrylics, specialty nylons, and other polymers and may open many opportunities for exploitation of chemical finishes for providing multi-functional finishes on cotton fabrics [34].

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Chapter 8

HEAT-SETTING

8.1 Introduction

Fabrics produced from synthetic fibres or from blends containing large proportion of such fibres are normally heat-set to stabilise them. Heat-setting is a heat treatment by which shape retention, crease resistance, resilience and elasticity are imparted to the fibres. It also brings changes in strength, stretchability, softness, dyeability and sometimes on the colour of the material. All these changes are connected with the structural and chemical modifications occuring in the fibre. An unset polyester filament yarn shrinks about 7% when allowed to relax in boiling water. This shrinkage is about 10% in the presence of carrier at boil. It is, therefore, necessary to confer on fabric some degree of dimensional stability in order that the yarns or fabrics retain their shape during subsequent processing, washing and ironing.

8.2 Thermal Behaviour of Synthetic Fibres

Synthetic fibres, mainly polyester and nylon, consist of long chain molecules and are held together by interchain bonds. Fig. 8-1 shows how the chains are ir-

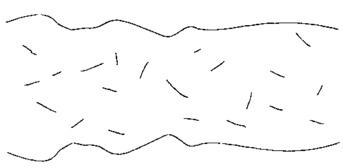

Figure 8-1. Probable disarray of polymer after spinning.

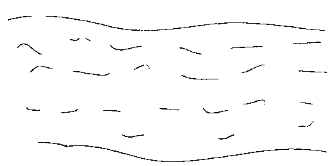

Figure 8-2. Parallel orientation of chain molecules in drawn fibre.

regularly distributed at random in single fibres immediately after spinning. The fibres are then stretched several times their original length to impart desirable properties to the fibre and this causes orientation of chain molecules parallel to the fibre axis (Fig. 8-2). The single chains are now held together by intermolecular forces, hydrogen bonding or by a combination of Van der Waals' forces and H-bonds. As a result of stretching the fibre molecules come closer to each other, resulting in closer alignment, increased density and thus increased H-bonding. The H-bonds are formed at random and there are strains between the chains. The single chains are, however, not yet completely stretched out and are still kinked having a zigzag configuration. If energy in the form of heat is supplied, the chain molecules starts vibrating, some of these interchain bonds break and some parts of the molecular chains have a greater freedom and relax. The temperature at which there is certain increase in molecular vibration of polymer molecules depends on Tg of the particular fibre. The higher the temperature the more interchain bond breaks and greater the relaxation, but care has to be taken not to heat the fibre so as to damage it. The supply of energy is stopped as soon as the minimum potential energy is reached and the fibres are cooled as quickly as possible, one succeeds in ''freezing'' the H-bonds. The newly formed bonds are more difficult to break and the fibres are dimensionally stable and will not shrink at approximately 10°C below the temperature of setting. At this juncture the process temperature commences to produce a new heat memory and Tg is changed. Thus the process of thermosetting in stenter can be broken down into four distinct phases :

i) The goods are run wet or dry into the machine and heated superficially to the heating temperature (heating phase).
ii) The heat penetrates the fibres untill all points, inside and out, are at the same temperature (penetration phase).
iii) Heating of the fabric to a temperature which is specific for each fibre, ensuring breakage of intermolecular bonds and equalising internal stresses (transition and stretch phase).
iv) Cooling the fibre resulting in the restoration of intermolecular bonds which are free from internal stresses (cooling phase).

8.3 Stages of Heat Setting

Heat-setting can be carried out at three different stages in a processing sequence i.e. in grey condition; after scouring; and after dyeing. The stage of heat-setting depends on extent of contaminations and types of fibres or yarns present in the fabric.

If heat-setting is carried out in the loom state, mineral oils and non-ionic emulsifiers can modify the fibre structure and rubbing and perspiration fastness may be reduced due to the solubility of disperse dye in the coning oil [1-4]. PVA size above 135°C looses its Tg which is followed by becoming crystallized and melts. The H-bonds, therefore, can no longer be broken with the result that PVA becomes difficult to remove from the fabric. However, grey heat-setting is useful in the warp knitting industry for materials that can carry only small amount of lubricants and for goods that are to be scoured and dyed on beam machines. The other advantages of grey heat-setting are : yellow colour due to heat-setting can be removed by bleaching, fabric is less sensitive to crease formation during subsequent processing etc.

Heat-setting can be carried out after scouring if it is suspected that the goods will shrink or for the cloth in which 'stretch' or other properties are developed during a carefully controlled scouring process. However, this stage requires drying the cloth twice.

Heat-setting can be carried out after dyeing also. Post set fabrics show considerable resistance to stripping compared with the same dyeing on unset fabric. The disadvantages of post setting are : yellow colour developed cannot be removed any more by bleaching, handle of the cloth may get altered and there is a risk of colours or optical brighteners be faded somewhat.

8.4 Methods of Heat-Setting

8.4.1 Contact method

In this method the fabric is run in contact with a heated metal surface. Some machines are composed of metal rollers having gas fired cores and are filled with a liquid known as diatherm to uniformly distribute the heat. Sometimes enclosed rollers are heated with high temperature steam. This method is mainly used for heat-setting of polyester/cotton blended fibre fabrics. Though heat is used efficiently in this method, the width of the fabrics cannot be controlled while fabrics run flat against the roller surfaces, apart from variation in degree of setting caused by variation in tension.

8.4.2 Steam-setting method

Short staple polyester yarns including polyester/cotton blends are normally set by relaxation in saturated steam. The most effective means of stabilising these materials are to steam at 107°C on the ring spinners tube and soft dyeing packages under minimum tension. Steaming is carried out in an autoclave fitted with vacuum pump, e.g. two times 15 min at 125-135°C with intermediate evacution or alternatively, for 60 min with saturated steam. Sewing threads receive special setting treatments, designed to confer stability whilst preserving their high tensile properties. Polyester garments, garment lengths and hosiery are also stabilised by steaming in much the same way as for yarns.

Nylon can be set in saturated steam at temperatures above 100°C in an autoclave by batchwise process. Nylon yarn is wound on to a collapsible paper tube or cross-wound in cheese form to a spring core and is treated in steam for 30 min cycles, vacuum/steam 5 to 20lb/in^2/vacuum and rewound on to the spring in the case of paper tube. For textured nylon yarn similar packages can be used but the package density is very much lower. Woven or warp knitted nylon fabrics are batched in open-width on to a perforated roller and setting cycle commences by a vacuum exhaustion down to a pressure of 28 inches of Hg. Saturated steam is then injected at the desired temperature and treatment continued for 10 min. This is followed by a further vacuum exhaustion and prolonged steaming cycle of 20 min at selected temperature. A final vacuum exhaustion completes the process. In the case of hose and half-hose, the goods are framed onto metal formers on which the goods are shrunk during steaming operation. Typical steam setting conditions are 115°C (10lb/in^2) to 130°C (25 lb/in^2) for nylon 6,6 and 108°C (5 lb/in^2) to 121°C (15 lb/in^2) for nylon 6. Steam setting increases the build up of acid dyes and unlevel dyeings will result if the temperature varies throughout the batch.

8.4.3 Hydro-setting method

The hydro-setting or aqueous heat-setting of polyester is done with hot water in a high temperature liquor circulating machine at about 130°C. A typical cycle may require 30 min. Water (or steam) promote swelling of fibre and may cause some hydrolysis in the ester groups in polyester chain. This causes partial destruction of intermolecular bonds and depolymerisation of fibre with a result in loss in tenacity. However, the hydrosetting temperature can be lowered by adding some selected organic or inorganic substances causing swelling of polyester, but such conditions have not yet found industrial application.

Nylon fabric can be hydro-set in hot water since the swelling action assists in weakening or breaking intermolecular bonds. The fabric in flat form is batched onto a perforated metal cylinder and immersed in hot or boiling water for a short period of time. Hydrosetting at boil is roughly equivalent to dry setting at 185°C. The texturised and tubular knitted fabrics are suitable as the fabric quality depends greatly on the methods of application. After setting in boiling water polyester is further shrunk by 11-12% on exposure to hot air at 200°C. Unlike polyester, nylon fabrics if set (relaxed) with boiling water shrinks only 3-4% on subsequent exposure to hot air at 200°C.

8.4.4 Heat-setting using tenter frame

Stenters are widely used for stretching, drying, heat-setting and finishing of fabrics (Fig. 8-3). Woven and knitted fabrics of polyester and nylon fibres and

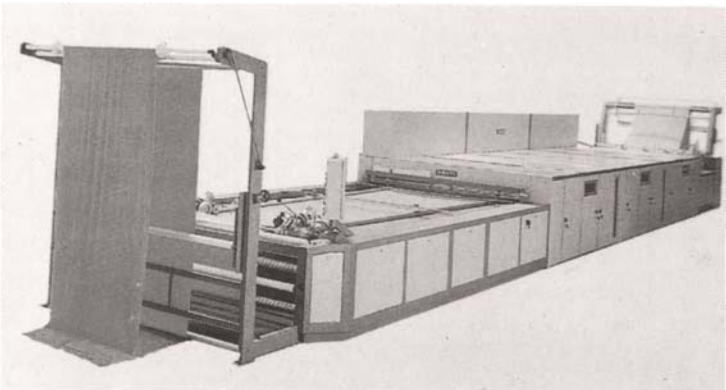

Figure 8-3. Stenter for drying, finishing and heat-setting knitted and woven fabrics (Courtesy of Monti s.p.A.).

their blends are normally heat-set on pin-stenter in hot air. An alternative to the pin stenter is the clip machine. The fabric is held into the chains either by pins mounted into a base plate or by clips in which the fabric edge is clamped between two smooth surfaces. Stenters that are used for setting only have a light pin chains whereas stenters used for both drying and setting (finishing) are provided with a heavy combined pin and clip chain. For knit goods vertically running pin stenter chains are particularly suitable. In order to be suitable for drying and setting purposes, the stenter rails are divided into three sections and can be moved laterally about the centre line. The entry section consists feeding in, with padding mangle, selvedge uncurler (for knitted goods), shrinkage apparatus (up to 30%), selvedge feeler for automatic correction of width and instrument panel with all switches. This section is usually about 5 m long for woven fabrics and 7 m for warp knits. The centre section is as long as oven, which may have from 3 to 8 heating chambers (sections), each about 3 m long. There should be at least two setting fields. The delivery section is about 4-5 m long to permit sufficient cooling to take place before the fabric is stripped off the pins by a roller and either rolled or plaited. On some machines an air blower is fitted after the heating sections to force cool air onto the fabric. The stenter frame is usually 80-100 feet long and 70-100 inches wide. The speed ranges from 10-45 m/min with a maximum setting time in the setting zone 30 sec at temperature ranging from 175 to 250°C depending upon the thickness and type of the material.

The stenter chambers should be thoroughly insulated from all sides and rest freely on pedestals. The choice of heating system used-direct gas, indirect steam or oil heating or electrical heating-depends on the customer's requirements. Since air is the transport medium for heat, thus as the air velocity decreases, available energy in the form of heat also decreases. Different systems, namely Puffer, Krantz, Jet etc. are used for circulating air around the cloth. In conventional air flow systems, fresh air is fed seperately to each compartment in a stenter, and the exhaust is similarly extracted seperately from each compartment. The demand for multilayer stenter (Fig. 8-4) is increasing. By combining a multi-layer stenter with the con-

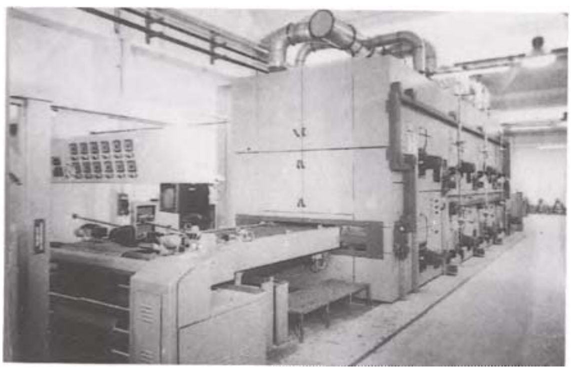

Figure 8-4. Multi-layer stentering machine (Courtesy of Bruckner GmbH).

ventional entry and exit of single-layer stenter it is possible to obtain operating flexibility. The main advantages are the avoidance of longitudinal distortions and the ease of operation and maintenance with this ground level arrangement. The multi-layer stenter is available in versions with 3 or 5 fabric passes (layers).

The shrinkage in length and width may be as much as 10% and this must be taken into consideration in determining the overfeed and the adjustment of the width. Most of the stenters make provision for overfeeds – 5% to + 40%. If the entry rollers feed the cloth at a slower speed, the cloth will be actually pulled by the travelling chains, thus gaining in length, but may correspondingly lose the width. Thus, slightly under fabric can be reduced to the required width by having positive speed difference and slightly narrower fabric can be brought to its required width by lessening the speed difference and increasing the widthwise pulling action. The extent to which overfeeding can be effected depends on fabric texture, construction, weave, fibre component, closer or broad coarses and wales in knit goods. Polyester knit goods should not be stretched more than 5% wider than the desired end width. An overfeed of up to 20% (generally 6-10 %) is commonly used in knit goods or texturised fabrics in order to level out variations in tensions caused by knitting. For woven goods an overfeed of 5 to 7% is generally sufficient. The overfeed device mechanism varies from make to make of stenter. Some have electrical device (e.g. Artos) whereas others make use of mechanical device (e.g. Primatex). It is also possible to adjust differential overfeed for right and left selvedges to correct distortions.

Knitted fabric finishing still has considerable rationalisation, reserves to offer especially in the fields of process and recipe optimisation. The principal processing problems are inadequate elimination of wash shrinkage; the phenomena of skew and bow distortion; and the poor reproducibility and frequent impairment of the look of the fabric. It is essential to work at the lowest possible tension and with short, contact-guided fabric paths with vertical chain return. This maintains a smaller gap between the upper traction roller and pinning device than with horizontal chain return. The vertical transport chain, designed for speeds of up to 140 m/min, can continuously maintain the production speeds required in knitted fabric finishing. An easy running compensator, developed specially for knitted fabric finishing, allows for speed regulation with extremely low fabric tensions by comparison with conventional dancing roller combinations. From the traction roller, the knitted fabric is fed via a very short transport path to the overfeed unit with specially developed brush belts, which press the edges of the knitted fabric into the pin plates with uniform ''gather'', even at rates of 50%. When feeding dry fabric it is advisable to insert a steamer using saturated steam in the entry section for uniform homogeneous moisture distribution. Widthwise contraction of up to 50% can be smoothly extended without any fear of centre and selvedge breakage. Production speed can be considerably boosted by the use of infra-red radiators (dryer) before drying. The Convey-Air nozzle system produces a special supporting effect and ensures absolutely uniform ''floating'' of the fabric, permitting permanent rapid relaxation of the fabric before the setting process proper. Methods of supporting knitted structures during stentering include the use of air cushions, endless belt or other supports [6-9]. Stenters considered to be particularly suitable for the processing of knitted fabrics have been described [10-13]. They include drum stenters [14] and stenters capable of processing fabric in either open-width or tubular form [15]. Heat-setting calenders may also be used for the treatment of tubular fabric [16].

Many important advances have been made in the design of control equipment for stenters include methods of measuring weight per unit area [17,18], moisture content [19] and fabric temperature [20]. The recommended method for checking the temperature is to secure thermoelements or thermopapers to piece goods passing through the stenter. Improvements have also been made in methods of feeding fabric to the stenter [21, 22].

8.4.5 Selective infra-red emitters method

Polyester can be heat-set by exposing the material under selected areas of magnetic spectrum of infra-red rays. The wavelength of the radiation source must be chosen with respect to the absorption band of the fibre i.e. a particular infra-red wavelength is chosen for a particular fibre. For example, in the case of polyester the selective infra-red radiation wavelength is the region of 1 to 4 μ. The radiations of wavelength of 1 to 2 μ passes freely through the polyester fabric and that of 3 to 3.5 μ are practically completely absorbed by polyester. Because of this absorption, it can be assumed that the energy is given up to the interior fibre structure, while emissions below this range are dissipated elsewhere. Such radiation sources and filters which closely approach the requirements, are now developed and are called ''selective emitters''. The absorbed energy is redistributed within the structure of the fibre, H-bonds and Van der Waals' forces binding the molecules together are disrupted and these disrupted molecules are at liberty to rearrange themeselves into positions of lowest energy (least stress).

Setting machines with infra-red selective emitters are designed in a manner which permits infra-red waves to be generated at temperatures in the 100 ± 20^0C range. The machine allows continuous processing and consists of an entry stand, a setting chamber with vertical rows of infra-red burners, an adjacent cooling zone and a delivery device. The distance of the burners from the fabric can be adjusted. One such machine is Polyfix machine (Timex, France) and can operate at speeds from 15 to 50 m/min and is available in different working widths. As a rule these machines do not control warp and filling tensions. However, these devices can be used within tenter housings and necessary controls can be done indicated under tenter frame.

8.5 Heat-setting Conditions for Different Kinds of Fibres

There are various kinds of synthetic fibres structurally with different melting points and with different heat-setting conditions. Even a slightest variations in heat-setting conditions, namely temperature, time and tension influence the setting effect, regardless of the system used.

8.5.1 Polyester fabrics

Polyester piece goods are pre-set with hot air on pin stenters for 20-40 sec at 180-210°C according to the type, density and weight of the material, with minimum tension on the goods to control the dry heat stability to less than the accepted 1% shrinkage [23]. Heavier fabrics like suitings require more time as fabric heating time is more. Plain fabrics, woven from unset yarns may be expected to shrink by approximately 5% in warp and weft during scouring process and their residual potential shrinkage range from 4.5% to about 11% over the temperature range of 150 to 220°C. Staple fibre fabrics shrink less than filament fabrics and stability adequate for apparel fabrics is conferred by setting at 170 to 180°C. Polyester fabrics are effectively dimensionally stable if it is set at a temperature of 30 to 40°C higher than the temperature to which the fibre is subjected to expose during subsequent processes.

8.5.2 Nylon fabrics

The setting conditions used for different nylon fabrics vary depending upon the melting point of nylons, heat-setting methods, rate of transfer of heat and the weight of the cloth being processed. For practical purposes, the conditions of hot air setting being used for different nylons are shown in Table 8.1. An overfeed of 2-3% is normally required but this has to be determined before-hand depending upon the handle and structure required.

On steam injection stenters the heating medium is a mixture of super-heated steam and air. The superheated steam required for the purpose can be generated inside the chamber by injection of saturated steam. In this mixture total heat capac-

TABLE 8.1
Heat-setting Conditions for Different Nylons

Type of nylon	Time of contact (sec)	Temperature of setting (°C)
Nylon 6	15-20	190-193
Nylon 6, 6	15-20	200-230
Nylon 11	15-20	≃ 150
Quina	15-20	190

ity of the medium is increased considerably because the specific heat of steam-air mixture is almost twice the air alone and the fabric can be set at a running speed of 60-70 yds/min. Warp knitted and light woven fabrics require only 3-4 sec compared to 15-20 sec with hot air alone. Apart from this, steam-air mixture also scavange the air from the setting chamber and thus reduce the oxidation degradation and minimise stiffening and yellowing of nylons. However, this system requires a highly efficient insulation of the heat-setting chamber to minimise corrosion.

8.5.3 Texturised polyester and nylon fabrics

The choice of setting conditions for bulked yarn materials depends on the type of bulking process that have been employed. In general, high tension must be avoided during heat-setting process, because of danger of pulling out the bulking effect.

Woven fabrics made from texturised polyester yarns should be heat-set for 20-30 sec at 160°C with slight width extension to remove creases, but without true overfeed so as to avoid the production of rippled selvedges. Higher setting temperatures (e.g. 165-170°C) may be required to control the tendency of some fabrics of tighter construction to crease during jet dyeing, but these temperatures can cause some loss of yarn bulk and tend to give a modified, leaner handle. Knitted goods are composed almost exclusively of textured yarns. Polyester double-jersy fabrics, weft knitted from stabilised bulked filament yarns may be heat-set on a stenter for 30 sec at 150°C. The goods should not be stretched more than 5% wider than the desired end width. An overfeed of up to 20% can be given for knitted goods.

For texturised nylon, after relaxing heat-setting is normally done at 150-160°C for 30 sec in a hot air stenter with an overfeed of 10-15%. The overfeed can be increased to 15-20% depending upon the type of stretch. The heat-setting temperature is always kept below the temperature of texturisation. Nylon can be heat-set only once [25, 25] and differs in this respect from polyester fibres, which can be repeatedly heat-set at progressively higher temperatures. This is of particular importance in the processing of knitted fabrics produced from textured yarns since such yarns have already been permanently heat-set. For any knitted structure a minimum energy state exists and if a knitted structure is allowed to relax after stretching, it returns to the equilibrium condition [26]. Since the setting effect obtained with fabrics knitted from textured nylon is essentially temporary, ideally the fabrics are set under relaxed conditions. It is not always possible to do this. However, the fabrics may be set within 5-10% of relaxed dimensions which will normally shrink less than 5% [27]. Alternatively, heat-setting in knitted fabrics can be brought about by preventing the changes in length of yarn in each loop and in the shape, curvature or degree of intermeshing of the loops [28].

8.5.4 Acrylic and modacrylic fabrics

These fibres cannot be heat-set in the conventional sense since the fibres are readily stretched or deformed at temperatures above 75°C. The degree of stability, however, can be obtained by passing these fabrics through a hot air stenter at about 120°C. Temperatures above 120°C may cause discolouration of the fabrics. For blended fabrics containing acrylic and modacrylic fibres higher heat-setting temperatures may be required. Knitted fabrics produced from a feeder blend of acrylic and textured polyester fibres, are heat-set at about 160°C for 30 sec.

8.5.5 Cationic dyeable polyester fibre fabrics

Cationic dyeable polyester (CDPET) and regular polyester fibres differ much in chemical properties. Generally, CDPET has a slightly lower heat resistance than the regular PET, so that heat-setting temperature for CDPET is kept slightly lower than that of normal PET. Table 8.2 shows the approximate heat-setting conditions of different polyester fibres.

8.5.6 Triacetate fibres

An important property of triacetate fibres is the ability to undergo structural changes under the influence of heat. Triacetate is not effected by dry heat up to 150°C. The fibre becomes increasingly plastic between 150 to 190°C and at still higher temperatures up to 220°C molecular reorientation occurs to an increasing extent accompanied by increase in crystallinity so that imbibation of the fibre falls from 16 to 10% and there is corresponding reduction in absorption and desorption

TABLE 8.2.
Approximate Heat-setting Conditions of Different Polyesters

Type of Polyester	Heat-setting Temp. (°C)	Contact time (sec)
100% Polyester (normal)	180-220	20-40
CDPET	170-180	20.40
Carrier-free dyeable PET		
(a) Polybutylene terephthalate, Type - 1	160-180	30
(b) Dicarboxylic acid, Type-2	170-190	30
(c) Copolymer, Type-3	190-200	30

of dyes. A permanent change in thermoplastic behaviour takes place and the fibre becomes increasingly less plastic. Table 8.3 shows the extention figures of triac-

TABLE 8.3.
Thermoplastic Behaviour of Triacetate Fibres

Temperature (°C)	% Extention (under load of 0.02 g/den)	
	Normal triacetate	Triacetate after treatment at 200°C for 5 min
20	0.10	0.10
140	0.10	0.10
160	0.15	0.10
165	0.40	0.10
175	1.10	0.20
185	3.00	0.70
190	8.00	1.00

etate fibres. Similar results can be obtained if triacetate is exposed to combined effect of heat and moisture at temperatures lower by 60-70°C than when dry heat is used only.

8.5.7 Polyvinyl chloride fibres

The outstanding property of these fibres is the shrinkage on heating which enables the manufacture of various specialty products. The fabric can be heat-set by passing it through a hot air stenter with necessary overfeed. Normal feeding, which gives shrinkage in the weft direction, can be done in one passage at 95°C at a speed depending on the fabric construction. Shrinkage can also be allowed to take place during or after dyeing. Materials containing fibres with inherent shrinkage should be processed at temperatures not exceeding 70°C. Pre-shrunk fabric can be wet pre-treated at 96-100°C.

8.5.8 Elastomeric fibres

Fabrics containing elastomeric fibres can be heat-set. A tricot or sleek-knit fabric knitted from nylon 6 and polyurethane may be satisfactorily heat-set at 180-185°C for 20-25 sec. Slightly higher temperatures (190°C) may be used for nylon 6,6. However, the required width and stretch characteristics of the finished fabric determine the precise conditions to be employed with a particular fabric [29].

8.6 Heat-setting of Blended Fibre Fabrics

New fibres and newer blended fabrics have been produced and these are also to be heat-set for successful dyeing and finishing operations.

8.6.1 Polyester / cotton blends

Short staple polyester fibres are often blended with cotton or some other cellulosic fibres. Normally heat-setting in stenter with hot air is carried out at 180°C for 30 secs. Higher temperatures may discolour the cellulosic portion of the material. For increased stability, setting may be carried out even at 200°C for 30 secs without serious risk of damaging the cellulose. The free weft-shrinkage of a typical polyester/cotton shirting fabric is about 4% at its normal setting temperature, but this is restricted to 2-3% (i.e. 1-2% residual shrinkage is allowed) in order to ensure the removal of creases and to get control over weft straightness.

8.6.2 Polyester/wool blends

Polyester/wool blended fabrics are normally heat-set before dyeing. Similar effect is obtained on the wool component on the blend by crabbing. Polyester/wool blended fabrics can be heat-set in a hot air stenter for 30 secs at 180 ±10°C. For worsted-spun goods 3-5% relaxation shrinkage is allowed both warp and weft and for woollen-spun materials 1-2% is allowed. The wool should be allowed the normal moisture regain before heat-setting [30]. For blends containing more than 40% polyester content, heat-setting is done with adequate overfeed to avoid shrinkage during dyeing operations. Top dyed wool rich blend qualities of polyester/wool fabrics having wool content above 67% need not be heat-set as adequate dimensional stability can be imparted by autoclave decatising popularly known as K.D.Finish. After setting, the goods may be damped or steamed to restore normal equilibrium moisture content of the wool as rapidly as possible. The sequence of operations is slightly different, according to whether a clear-cut or milled finish is required; for clear-cut finishes, heat-setting may either precede or follow dyeing. For milled finish, it is recommended to carry out heat-setting after milling and dyeing. Singeing should follow heat-setting, unless the fabric is to be milled, when singeing precedes heat-setting.

8.6.3 Polyester/linen blends

Polyester/long-staple fibres are also used in the linen industry, where the yarns may be of either the 'stretch-broken' or 'unbroken' type, but are more commonly of the latter. Heat-setting of such fabrics may be carried out at 180°C for 30 secs on the hot air pin stenter, allowing up to 2% weft shrinkage with overfeeding only to compensate for any warp shrinkage that has occured in the previous process.

8.6.4 Polyester/silk blends

Heat-setting of polyester/silk fibres blended fabrics can be carried out on stenter at 190°C for 30 secs. The introduction of up to 50% polyester does not effect the characteristics drape and handle associated with silk fibres.

8.6.5 Polyvinyl chloride/cellulosic fibres blends

For blended fabrics with cellulosic fibres it is possible to produce heat-embossed blend fabrics with 25% polyvinyl chloride fibres. Heat treatment is carried out by one passage on pin-stenter without overfeed at 85-90°C, and if for example a 15-17% shrinkage is to be achieved, the speed of travel is about 10 m/min.

8.7 Effect of Heat-setting on Various Properties of Synthetic Fibres

8.7.1 Structural changes of polyester and nylon

Polyester is not a fast crystallising polymer. The rate of crystallisation is maximum for polyester at around 180°C. The maximum crystallisation rate for polyester is about 0.016/sec, while it is 0.14/sec for nylon 6. The following changes take place as a function of increasing temperature in polyester when heat-set under free to relax conditions (i.e. free annealing) and when held taut at constant length (i.e. taut annealing) :

i) Crystallinity increases with increasing temperature in both the cases, but is more for free or slack annealed samples at all temperatures.
ii) Crystal size increases in both cases.
iii) Crystallite orientation and birefringence increase in case of taut annealed samples, but decrease in case of free annealed samples.
iv) Amorphous orientation decreases in both the cases. In free annealed sample the decrease is greater due to shrinkage allowed.
v) The number of crystals in the fibre increases but at higher temperatures, the crystals fuse together and their total number decreases and crystals become perfect.
vi) Amorphous volume per crystals first decreases and then increases in both the cases.
vii) The glass transition temperature first increases and then decreases with increasing heat-setting temperature.
viii) Increasing tendency for phase seperation at high heat-setting temperatures is possible.

Heat -setting processes result in inner changes in the amine end group content of nylon fibres and such changes will only slightly modify the uptake of acid dyes. The density and crystallinity of nylon increase on setting both in dry heat and in saturated steam. Application of tension assists in the development of crystallinity. When heated under tension orientation increases. The increased orientation is lost, however, by allowing the stress in the fibres maintained under tension to relax. Crystallinity and crystal size increase more readily at a lower temperature for steam set sample compared to dry set samples. The orientation of the crystalline regions resulting from both types of heat-setting show similar trend whereas the orientation of amorphous regions of the wet set material increase rapidly with the setting temperature. The modulus of the fibre increases on dry heat-setting and it decreases on steam heat-setting. Increase in modulus occurs, if heated under tension. Shrinkage of the fibre decreases with heat-setting temperature and is related in an inverse fashion to the crystallinity.

8.7.2 Dimensional stability

The higher the temperature to which the yarn or fabric is exposed, the higher the resultant shrinkage over the temperature range of 100-200°C [31]. Figs. 8-5 and

8-6 illustrate the free shrinkage of a typical unset polyester yarn in hot, dry air and

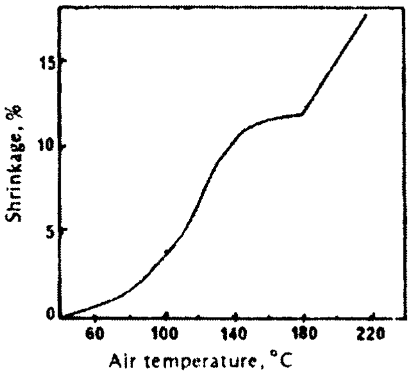

Figure 8-5. Free shrinkage of polyester yarn (medium tenacity), in hot air.

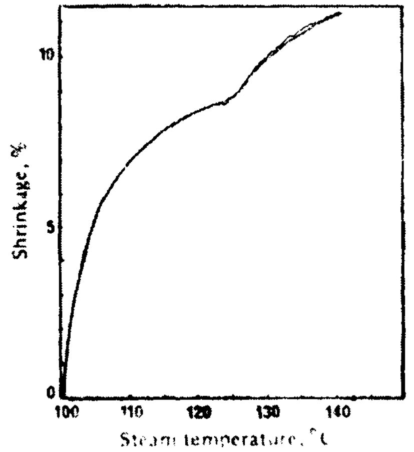

Figure 8-6. Free shrinkage of polyester filament yarn (medium tenacity), in saturated steam.

in saturated steam respectively. As the result of shrinkage, the mechanical properties of the fibre change so that its extensibility increases and breaking load diminishes without appreciably changing the work of rupture. Fig. 8-7 shows the effect

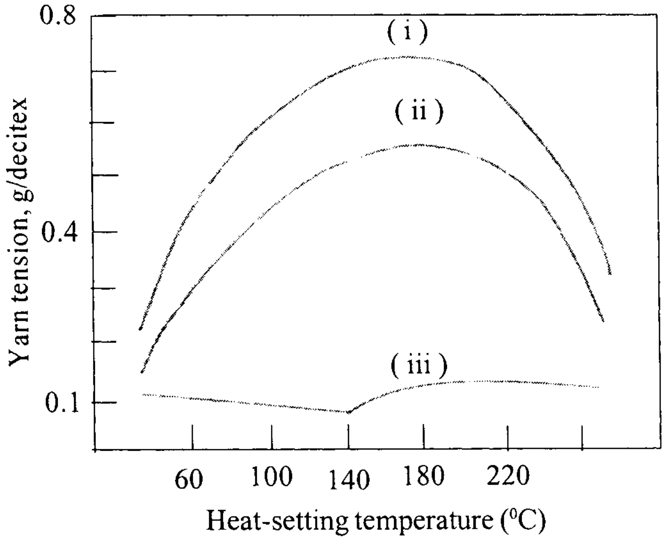

Figure 8-7. Tension produced in heat-setting at constant length. [(i) unset yarn, producer twist, 30 t.p.m.; (ii) unset, thrown, 300 t.p.m.; (iii) steam-set, thrown 300 t.p.m.].

of tension produced in polyester yarn on heat-setting at different temperatures. In general, the tension in the yarn at first increases but temperatures over about 180°C, it decreases steeply. The third curve (iii) of Fig. 8-7 represents the tension produced in a polyester yarn that have been twist set in steam at 110°C and the tension is unlikely to exceed 0.1 g/decitex unless the yarn is deliberately stretched [32].

In general, the higher the setting temperature, the lower is the resultant shrinkage of the heat-set fabric at any given temperature. The shrinkage of unset polyester fabric at 175°C is about 15% as compared to 1% for the same fabric set at 220°C. Fabrics containing both dyed yarns and unset yarn tend to show differential shrinkage effects, and these must be set at the highest temperature permitted by the sublimation fastness of the dyed yarns.

8.7.3 Stiffness

The setting process stiffens the fabric, which is undesirable. Higher the setting temperature, more is the stiffening. A fairly linear correlation exists between the stiffness and setting temperature [31]. The stiffening is due to the formation of continuous film on the fibre surface and high tension developed during setting. The stiffening effect is lost if the fabric is subsequently treated mechanically e.g. by dyeing on a winch. High tensions during setting leads to the production of a thin paper like and impoverished handle while free relaxation gives a soft and silky fabric. However, it is difficult to completely eliminate tensions and full relaxation also leads to considerable loss of yield. Also, tensions have the effect of removing yarn crimp. About 3-4% potential yarn shrinkage is restrained and the rest is allowed to freely shrink in the stenter.

8.7.4 Crease recovery

One of the purpose of heat-setting is to reduce the extent of creasing on subsequent dyeing and washing processes. The higher the setting temperature the less is the wet creasing. The degree of wet creasing, is however also related to fabric construction, for example, open or loose construction fabrics show better crease recovery than dense fabrics. High setting temperature which creates a degree of stiffness in the fabric does not recover well from creasing of dry polyester fabrics. Some compromise is necessary between the temperature necessary for maximum dimensional stability and that for an acceptable dry crease recovery.

8.7.5 Dyeability

Fig. 8-8 shows a typical disperse dye uptake at the boil without carrier in the

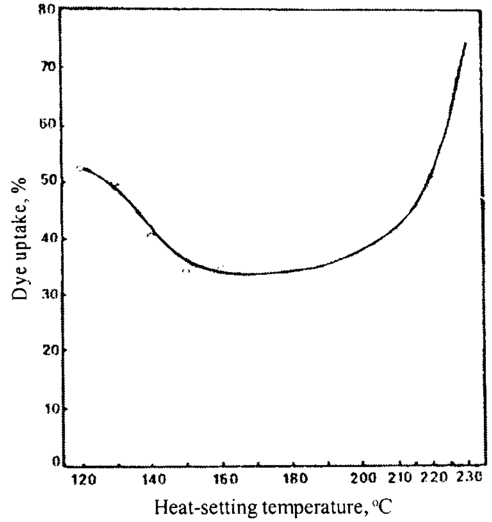

Figure 8-8. The effect of heat-setting temperature on dye uptake when polyester is dyed with C.I.Disperse Red 1 [33].

dyebath in which dye uptake varies with the setting temperature used when polyester is heat-set. Although this pattern of behaviour is general for all disperse dyes applied to polyester, the shape and position of the absorption curve depend on the method of dyeing [34] ; the size, planarity and polarity of disperse dye ; position of substituent groups and solubility of dyes [35]. The absorption of some dyes is practically independent of heat-setting temperature whilst absorption of others is highly sensitive to it [36]. As the setting temperature is increased, the curve shows a reduction in the rate of dyeing for setting temperatures between 130 and 150°C followed by a levelling-off. Above about 190°C, the rate of dyeing rises rapidly and eventually reaches values greater than that for unset cloth. The initial decrease in the uptake suggests that new crystals are formed as setting temperature is increased by coming together of well parallelised chains in the amorphous regions and amorphous volume per crystal decreases so the path for the dye particles through the amorphous region is very tortuous. In the later stages of crystallisation, the crystallites increase in size and also become more perfect. Thus at the higher temperature of setting, the amorphous volume per crystal increases. Chain folding also occurs giving rise to segregation of crystalline and amorphous regions. This results in less tortuous path for the dye and provide easy passage for the dye molecule. The degree of crystallinity affects the total amount of dye that can be absorbed, whereas the degree of orientation affects the rate of dyeing. Sharp increase in dyeability above 220°C is thought to be associated with disorientation of the fibre and cannot be employed on commercial scale because small differences in temperature may give uneven adsorption of dye and reproducibility of the results would be very poor. In addition tension, moisture and time of contact during heat-setting are also important factors that cause variation in the dyeing properties of the fibre.

The effect of disperse dye uptake on heat-set temperature of polyester is also attributed to the fibre being purified [37]. Purification has been visualised as being either the elimination of di -, tri -, and tetramers or their melting and coalesence to form greater distances between the bonds. The greater bond distances then provide for greater voids causing molecular voids. This is correlated between Tg and apparent transition temperature of dyeing.

Structural changes in nylon due to heat-setting affect the dye uptake. Steam treatments increase the uptake and rate of dyeing whereas dry heat causes some reduction. This increased dye receptivity and hence lower activation energies in steam heated materials may be attributed to the more open structure of set nylons. In the dry setting, the minima observed suggests that at the temperature at which decrease in dyeing properties occurs, the increase in crystallinity is important; however, the increase in dyeing properties at the higher temperatures suggests an opening up of the amorphous structure.

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