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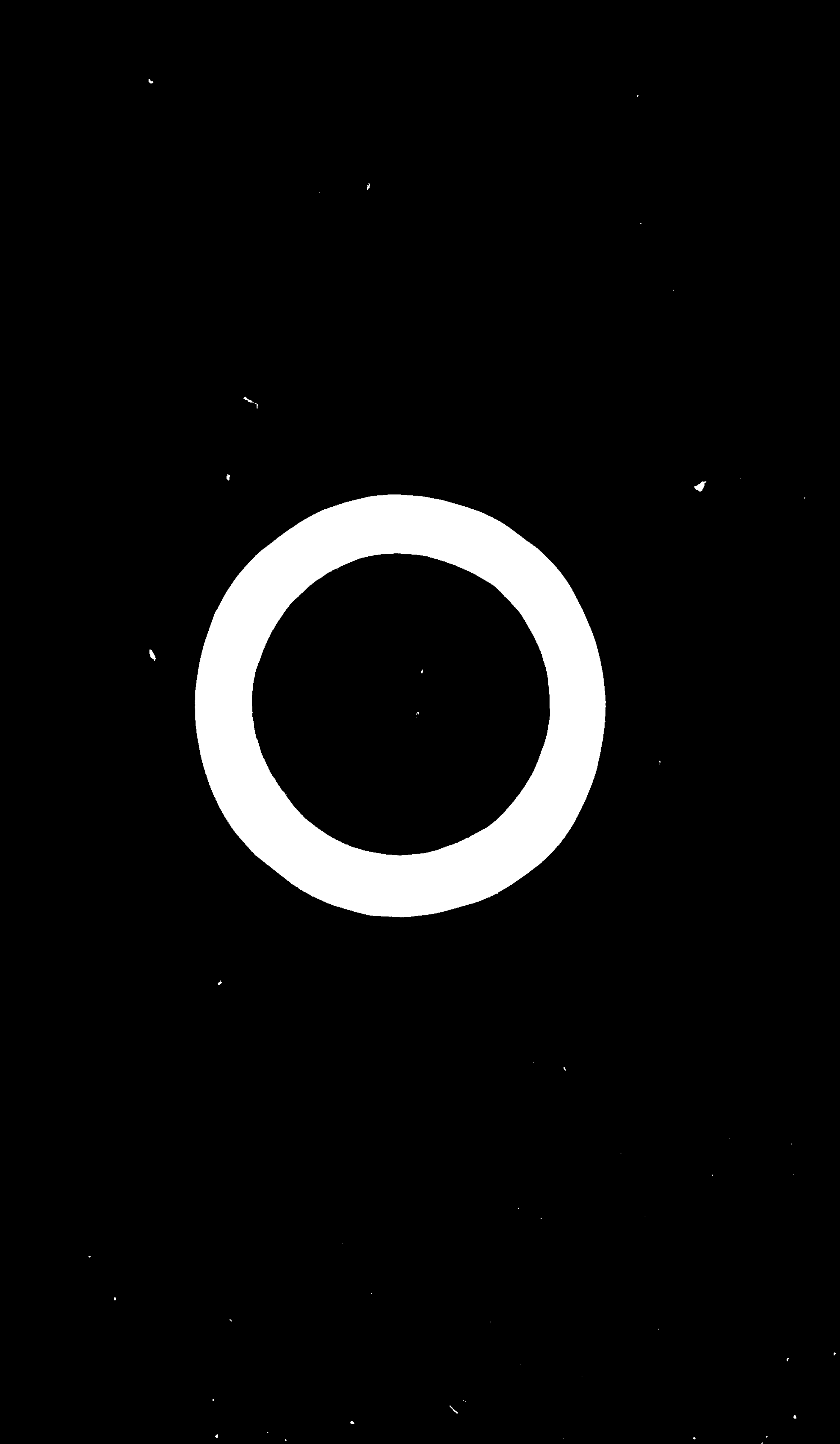
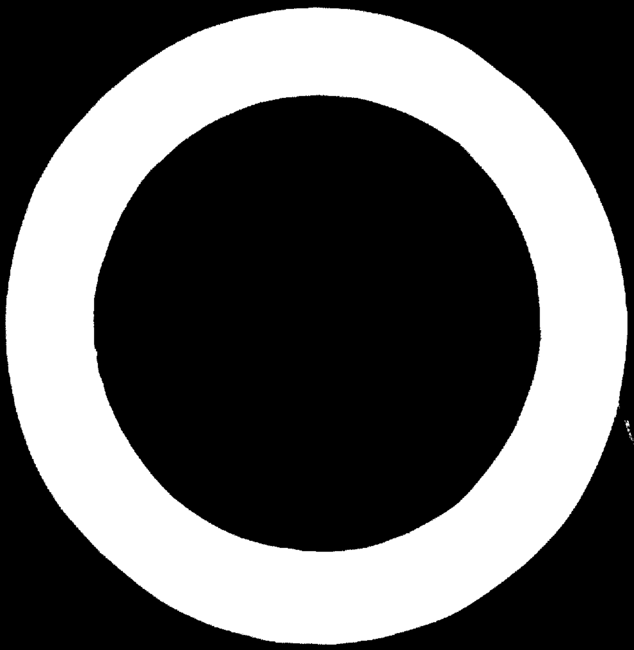
TRAINING FOR INDUSTRY SERIES NO. 3

THE ŁÓDŹ TEXTILE SEMINARS

6. Textile finishing

UNITED NATIONS





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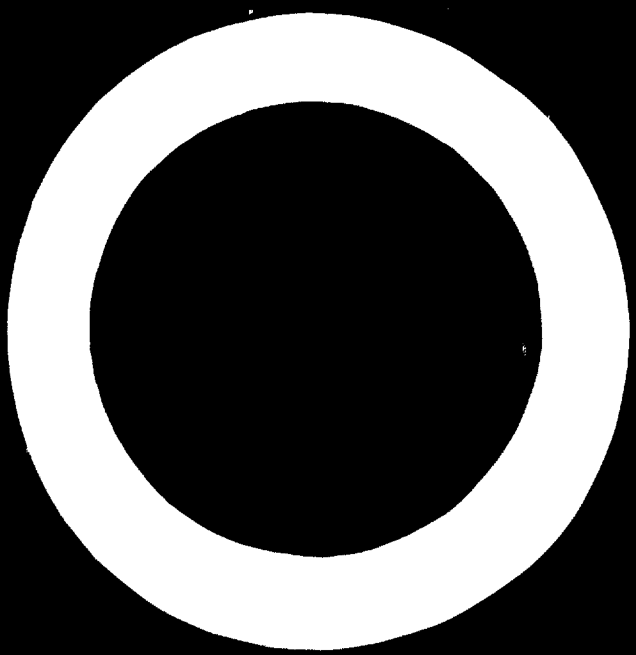

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

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FOREWORD

This publication is the sixth of a series devoted to textile engineering and closely related fields. It is part of the Training for Industry Series published by the United Nations Industrial Development Organization (UNIDO).

Rapid world-wide increases in population and industrialization are reflected in the textile and allied industries. In any ranking of human needs, fibres and textiles for clothing and industrial purposes are second only to foodstuffs. The continuing quantitative and qualitative changes in textile production require the broadest and most complete dissemination of information in this important area.

The purpose of the present series is to make available to the developing countries the most recent scientific and technical information in order to help them to establish textile industries or to improve the effectiveness and economic viability of existing textile industries that are still in the earlier stages of economic development.

At the suggestion of UNIDO, with the support of the authorities of the Polish People's Republic, a post-graduate in-plant training course in textile industries was held in Łódź from May through September 1967. The course was repeated from May through October 1968, and its content was modified and up-dated on the basis of experience and new information. It was repeated again in 1969 and it is planned to continue this programme, up-dating its subject matter and improving its usefulness to the textile industries of the developing countries. It is on these courses that the present series is based.

The courses were organized by the Textile Research Institute in Łódź with the object of training a group of already highly qualified specialists in all branches of industry relating to textiles. Under normal conditions, such training would require work in mills and in research and development over a period of several years.

The courses give the participants an opportunity to become acquainted and to do actual work in conjunction with some of Poland's leading research centres and industrial enterprises, and to discuss with experts problems connected with techniques, technology, economics, organization and research in the field of textiles. In organizing the courses, the Textile Research Institute endeavours to co-ordinate the content of theoretical lectures, technical discussions and practical studies in laboratories and mills, covering all the fundamental problems of textile industries.

The main object of the seminars is to adapt the broad range of problems presented by Polish specialists to the direct needs of the developing countries. Lectures by the research workers of the Institute formed the core of the programme. The lectures do not review or repeat the basic problems usually studied at technical colleges and high schools in the course of normal vocational training; rather, they deal with subjects most often of concern to the management and technical staff of a textile enterprise.

The lectures, as presented in this series, have been grouped in eight parts: textile fibres; spinning; knitting; weaving and associated processes; non-conventional methods of fabric production; textile finishing; testing and quality control; and plant and power engineering.

It is hoped that the experience gained from these courses, as presented in this series, will contribute to the improvement of textile industries everywhere, and particularly in the developing countries.

The views and opinions expressed in this publication are those of the individual authors and do not necessarily reflect the views of the secretariat of UNIDO.

CONTENTS

EXPLANATORY NOTES

References are indicated in parenthesis in the text, by name of author and year of publication. The full references are listed, alphabetically by author, at the end of each article.

References to "tons" indicate metric tons and to "dollars" ($), United States dollars, unless otherwise stated.

The following abbreviations have been used:

cpi means "courses per inch".

Denier (den) is the weight in grams of 9,000 metres of yarn.

gg is "gauge".

kcal is kilocalorie.

Metric count (Nm) is the number of kilometres of yarn per kilogram.

A nanometer (nm) is 10^{-6} mm.

rev/min is revolutions per minute.

Tex is the weight in grams of 1,000 metres of yarn; millitex (mtex) is 0.001 tex.

wpi is "wales per inch".

Worsted count is the number of 560-yard lengths per pound of yarn.

CHEMICALS AND DYESTUFFS

by

W. Szczepaniak

Numerous auxiliary agents, chemicals and dyes of different structure and properties are used in textile finishing.

For a better understanding of the finishing processes that are dealt with elsewhere in this publication, it is indispensable to consider carefully the basic properties of finishing agents, dyes and related products manufactured by well-known firms, and especially those products that are widely used in Poland.

Among the scouring and washing agents most frequently used for raw cloth and for dyed or printed fabrics are the following all of which are Polish made:

Sulfapol B: This is a light yellow paste that consists of anion-active sodium alkylbenzene sulphonate. It is used to wash fabrics made from cellulose fibres and blends that contain more than 50 per cent of these fibres. From 2 to 5 g/litre of this agent is used in aqueous solution for washing. It is also used as an additive to kiering lye in order to facilitate the wetting of the fibres.

Sulfapol TR: This is a brown, viscous liquid that contains an anion-active salt of triethanolamine and ceryl-benzenesulphonic acid, with an addition of non-ionic agents. It is used to scour woollen fabrics and blends of wool and synthetic fibres, and it also may be used as an additive to kiering lye.

Pretepon G: This is a light yellow paste that consists primarily of anion-active sodium alkyl sulphate. This washing agent is somewhat less efficient than the Sulfapols, but it has the advantage of giving woven and knitted fabrics a softer handle.

Alfenol 710: This is a brown, viscous liquid that contains a non-ionic condensation product of ethylene oxide and alkyl phenols. Solutions of Alfenol 710 can be mixed with washing, dispersing and finishing agents of all kinds, without causing any precipitation. It has high washing efficiency and is used for scouring fibres of all types.

Various agents are used in bleaching processes, depending on the chemical properties of the fibres treated. Agents suitable for bleaching various fibres are listed in table 1.

If the whiteness obtained by a chemical bleaching agent is not satisfactory, optical brightening agents may be used. Among these products are: Heliofor ZBC, recommended for cellulose fibres, and Heliofor ZSP, which is suitable for polyamide fibres. (Both of these products are Polish.)

Dyestuffs used for dyeing fibres may be divided into groups according to the similarity of their properties, the kinds of fibres that can be dyed with them, or the dyeing techniques with which they are used. The trade-names, manufacturers and countries of origin of some dyes of different groups are given in table 2, and the dyeability of various fibres is presented in table 3.

TABLE 1. SUITABILITY OF SOME BLEACHING AGENTS FOR VARIOUS FIBRES

Bleaching agents	*Fibres*									
	Cotton	*Viscose rayon*	*Flax*	*Wool*	*Silk*	*Acetate rayon*	*Poly-amide*	*Poly-ester*	*Poly-acrylic*	*Tri-acetate*
Sodium hypochlorite (NaOCl)	+	+	+			+				+
Sodium chlorite ($NaClO_2$)	+	+	+			+	+	+	+	+
Hydrogen peroxide (H_2O_2)	+	+	+	+	+					
Potassium permanganate ($KMnO_4$)				+	+					
Sodium hydrosulphite ($Na_2S_2O_4$)							+			

TABLE 2. TRADE NAMES, MANUFACTURERS AND COUNTRIES OF ORIGIN OF SOME IMPORTANT DYESTUFFS

	Federal Republic of Germany			*Poland*	*Switzerland*			*United Kingdom*
Dyestuffs	*BASF*	*Bayer*	*Hoechst*	*Ciech*	*CIBA*	*Geigy*	*Sandoz*	*ICI*
Acid	Ortol	Acilan, Supramin, Supracen, Isonal	Anthralan, Alizarin, Amidoecht	Acid-fast dyestuffs, Folan dyestuffs	Kiton (echt), Benzyl (echt), Alizarinecht	Erio (echt), Eriosin (echt), Polar, Neopolar, Irganol-S	Alizarin-brillant, Alizarin-walk, Lanasyn-rein, Xylenecht P	Carbolan, Coomassie, Lissamine

Metallized (type 1 : 2)[a]	Ortolan	Isolan, Levalan	Remalan-echt	Polfolan dyestuffs	Cibalan, Lanacron, Avilonlicht W	Irgalan, Irgaren-C	Lanasyn, Sandolan	Procilan (reactive)
Chrome	—	Diamant	Salicinchrom	Ortho-chrome dyestuffs	Chromecht	Eriochrom	Omegachrom	Solo-chrome, Solo-chromate
Direct (fast to light)	Lurantin	Siriuslicht (—LL)	Remastral	Helion dyestuffs	Chlorantin-licht	Solophenyl, Diphenyl-echt	Solar (3 L), Chloramin (echt)	Durazol
Reactive	Primazin (P)	Levafix	Remazol	Helactin dyestuffs	Cibacron	Reacton	Drimaren (-Z, -ZF)	Procion
Vat	Indanthren	Indanthren	Küpen, Indanthren, Hydron	Helantren dyestuffs	Ciba, Cibanon	Tina, Tinon	Tetra, Sandothren, Sandon	Durindone, Caledon
Sulphur				Sulphur dyestuffs	Pyrogen			Thionol (M), Carbindon
Soluble vat			Anthrasol	Helasol dyestuffs				Soledon
Pigment	Helizarin (NT)	Acramin	Imperon (K)	Poloprint dyestuffs			Printofix	

TABLE 2 *(continued)*

	Federal Republic of Germany			*Poland*	*Switzerland*			*United Kingdom*
Dyestuffs	*BASF*	*Bayer*	*Hoechst*	*Ciech*	*CIBA*	*Geigy*	*Sandoz*	*ICI*
Azo (components)		Naphtol AS, Echt . . . Base, Echt . . .	Naphtol AS, Echt . . . Base, Echt . . .	Naphto-elans, Naphto-elan bases,	Cibanaphtol, CIBA . . . Base			Brenthol, Brentamine fast . . . base,
		Salz	Salz	Naphto-elan salts	CIBA . . . Salz			Brentamine fast . . . salt
Developing azo		Rapidogen		Pologen dyestuffs				Brentogen
Disperse	Celliton, Palanil, Perliton	Resolin	Samaron	Synthen dyestuffs	Cibacet, Terasil	Setacyl, Setaron, Novalon	Artisil, Foron (-E, -SE, -S)	Dispersol, Duranol
Basic (acrylic fibre)	Basacryl, Acryl	Astra, Astrazon		Anilan dyestuffs	Deorlin	Maxilon	Sandocryl B	

[a]One metal atom per two molecules of dye.

TABLE 3. DYEABILITY OF SOME FIBRES

Dyestuffs[a]	*Cotton*	*Viscose*	*Flax*	*Wool*	*Silk*	*Acetate*	*Polyamide*	*Polyester*	*Polyacrylic*	*Triacetate*
Acid	—	—	—	+	+	—	●	—	—	—
Metallized (type 1 : 1)[b]	—	—	—	+	+	—	+	—	—	—
Metallized (type 1 : 2)[c]	—	—	—	+	+	—	+	—	●	—
Chrome	—	—	—	+	—	—	—	—	—	—
Direct	+	+	+	●	●	—	●	—	—	—
Reactive	+	+	+	+	+	—	+	—	—	—
Vat	+	+	+	—	—	—	●	—	—	—
Sulphur	+	+	+	—	—	—	—	—	—	—
Soluble vat	+	+	+	●	—	—	—	●	—	—
Pigment	+	+	●	—	—	●	●	●	●	●
Azo	+	+	+	—	—	—	●	+	●	●
Developing azo	+	+	+	—	—	—	—	—	—	—
Disperse	—	—	—	—	—	+	+	+	+	+
Basic (for acrylic fibres)	—	—	—	—	—	—	—	—	+	—

[a] Key: + most suitable dyes; ● alternatively suitable dyes; — unsuitable dyes.
[b] One metal atom per dye molecule.
[c] One metal atom per two molecules of dye.

For dyeing protein fibres such as wool and silk, the most suitable agents are acid dyes, metallized dyes and chrome dyes. Cellulose fibres, such as cotton, the rayons and flax, can best be dyed with the following dyestuffs: direct, reactive, vat, sulphur, soluble vat, azo and developing azo dyes.

Any given type of fibre will have a different fastness to water, washing, ironing, light, and the like, according to the dye used. For this reason, dyes should be selected according to the conditions under which the fabric will be used. In the case of protein fibres, the highest fastnesses are obtainable with metallized dyes and chrome dyes, while vat dyes are best for cellulose fibres. Pigment dyes are used primarily for printing fibres of almost all types, the highest fastness being achieved on cellulose fibres.

Synthetic fibres require special dyestuffs. Disperse dyes are suitable for all of them, and polyacrylonitrile fibres can be dyed with special basic dyes. Recently, it has become possible to use acid dyes for polyester and polyacrylonitrile fibres produced from special copolymers. This is a development of considerable importance.

The chemical compositions and trade-names of many textile finishing agents are given in table 4. The agents used for crease-resistant and shrink-proof finishes belong to the group of thermoreactive resins. In both of these cases the finishing process consists in impregnating the fabric with precondensates of these resins, which are

TABLE 4. FINISHING AGENTS

Finish	*Chemical composition*	*Polish products*	*Related products*
Crease resistant	Condensation product of urea and formaldehyde	Antimnol FM Antimnol WMS	Ureol P (CIBA) Kaurit KF (BASF) Kaurit W (BASF)
	Condensation product of melamine and formaldehyde	Melaform WM 100 Melaform WM 6	Lyofix CH (CIBA) Cassurit MPL (Casella)[a]
	Cycloethylene urea derivative	Silezan EM	Cassurit RI (Cassella), Fixapret CP (BASF)
Stiffening	Starch ether	Polvitex A, N	Solvitose HDF (Scholten)[a]
	Polyvinyl acetate	Winacet D-5	Apretan EM (Hoechst) Vibatex AN (CIBA)
	Polyacrylamide	Oktamid OAN	Texapret AM (BASF)
Flameproof	Emulsion of high chlorinated resin containing antimony oxide	Ogniotex CP	Aflaman (Quehl)[a]
Water-repellent	Pyridinium chloride containing a fatty chain	Hydrofobol IW	Velan PF (ICI)
	Melamine resin containing a fatty chain	Melafob S	Phobotex FT (CIBA)
	Stearic chromium complex	Hydrofobol CR	Phobotex CR (CIBA) Ombrophob C (ICI)

[a] Federal Republic of Germany.

contained in commercial products, and drying and curing them at a temperature of 140°C. Under these conditions, the resin undergoes cross-linking on the fabric under treatment, imparting the required properties to them.

Stiffening agents belong either to the starch ether derivatives or to the thermoplastic resins and are applied in the form of aqueous emulsions which, after evaporation of the water, produce a resin film, imparting the required stiffness to the fabric.

Flame-proofing agents usually consist of compounds that give off fire-extinguishing gases when touched by flame.

Water-proofing agents contain fatty chains that impart hydrophobic properties to the fibres, making them water-repellent.

The technical details on processes such as the washing, bleaching, dyeing, and finishing of woven and knitted fabrics are considered elsewhere in this publication.

BATCH-PROCESS MACHINERY FOR FINISHING AND PRINTING TEXTILES

by

W. Szczepaniak

There is a wide variety of textile dyeing, printing and other finishing processes performed by many different kinds of machines. Furthermore, any given process can be executed by equipment with quite different operating principles and operating efficiencies.

Textile finishing operations are performed continuously, semi-continuously or non-continuously, that is, by batches. In a continuous plant, the material is fed in and removed without interruption; in a semi-continuous plant, some operations are continuous and others are done in batches; in a non-continuous plant, the raw material or textile fabric is introduced as a single batch that is removed when treatment has been completed, and the processing cycle begins again with the introduction of a new batch.

While continuous and semi-continuous processing are more efficient than batch processing for large-scale, intensive production, the machinery required for them is more expensive than that for batch processing. Also, batch processing is more economic when production consists of a wide range of small lots.

Bleaching machines

The most important machines used for bleaching cotton and regenerated cellulosic fabrics are kiers and rope washing machines. Kiers, such as the boiling kier shown in figure 1, are steel vats into which the cloth is introduced, together with the boiling lye from a pre-heater, and uniformly packed. The boiling lye is pumped through the fabric, bleaching it and removing many impurities from the cellulose fibres. Some kiers, such as the one shown in figure 1, can be closed tightly and operate under pressure.

Rope scouring machines, such as the one shown in figure 2, are used for treating cloth with bleaching solutions or acid solutions or for rinsing it with water after each chemical treatment. The cloth, sewn into the form of an endless rope, is introduced into a tank at the lower part of the machine. After passing several times through the distance between the tank and the upper squeeze rollers, the cloth is extracted by the upper roller.

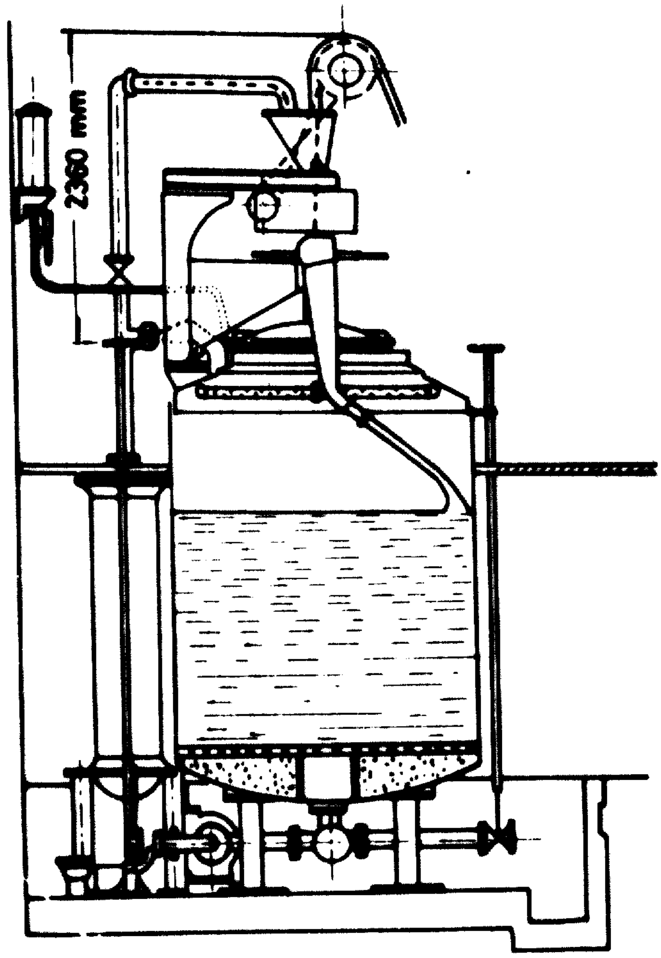

Figure 1. Mather-Platt boiling kier (United Kingdom)

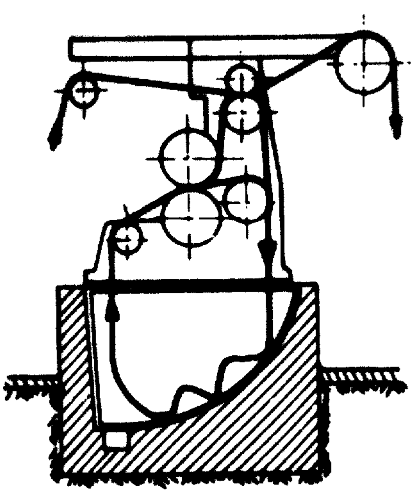

Figure 2. Textima rope scouring machine (East Germany)

Dyeing machines

The machines most commonly used in batch dyeing are winch dyeing machines and jigs. A winch dyeing machine consists of a bath, above which are a winch and a carrying roller. The cloth is introduced into the bath and drawn over the winch and the roller. Its ends are sewn together, giving it the form of an endless rope. The bath may be filled with a dye solution, a washing solution or clear rinsing water, as required. The rotating winch causes the fabric to move through the bath.

For dyeing light woven fabrics made from regenerated cellulosic fibres or from synthetic fibres and for light knitted fabrics machines with elliptical winches are used (figure 3). For heavy fabrics, primarily woollens, machines with circular winches are used (figure 4).

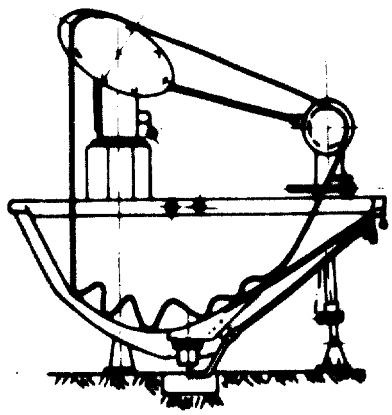

Figure 3. Type BC2 winch dyeing machine for light fabrics (Poland)

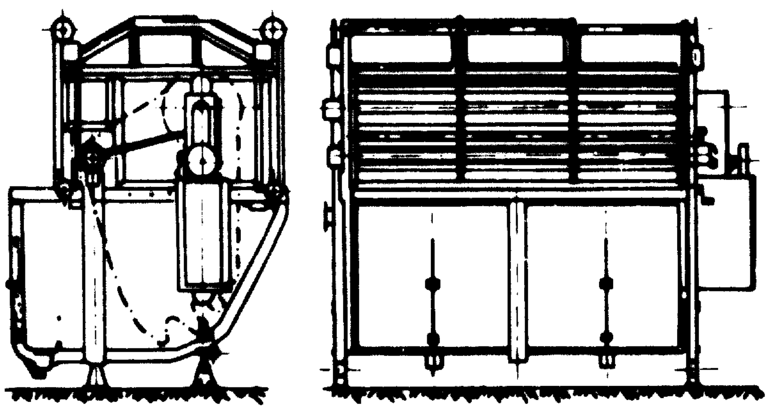

Figure 4. Type BC3 winch dyeing machine for heavy fabrics (Poland)

Some fabrics, such as cottons, are subject to wrinkling if dyed in rope form. Such fabrics are dyed in open width on a machine called a jig (figure 5). This machine consists of a trough that contains the dye-bath, at the bottom of which are two guide rollers (1), and at the sides of which are tightening rollers mounted on hanging arms (2), and two drive rollers (3). During dyeing, the fabric, in open width, is wound around these sets of rollers. By the alternate clockwise and counterclockwise rotation of the drive rollers, which is controlled automatically, the fabric is pulled back and forth through the dye-bath, complete immersion being ensured by the guide rollers.

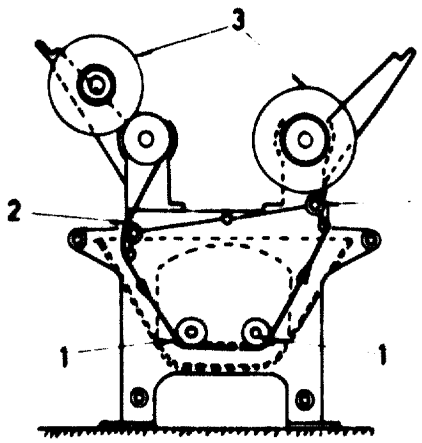

Figure 5. Jig for dyeing fabric in open width (see text)

Printing machines

Fabric printing machines are of three basic kinds: those using rollers, those using flat screens and those using cylindrical screens. While roller printing requires preparation of expensive rollers, this system is well suited for printing simple patterns on large amounts of fabric. Flat-screen printing uses relatively inexpensive screens of low durability. This system is thus suited for printing complex patterns for short runs. Cylindrical-screen printing combines the advantages of the other two systems. Throughout the world, roller printing is declining, while the number of screen printing machines is rising steadily.

The operation of a typical roller-printing machine is shown in figure 6. The continuous line (————) represents the path of the fabric being printed; the discontinuous line (- - - - -), the path of the background; and the discontinuous dotted line (-. . . . .) the path of the printing cloth.

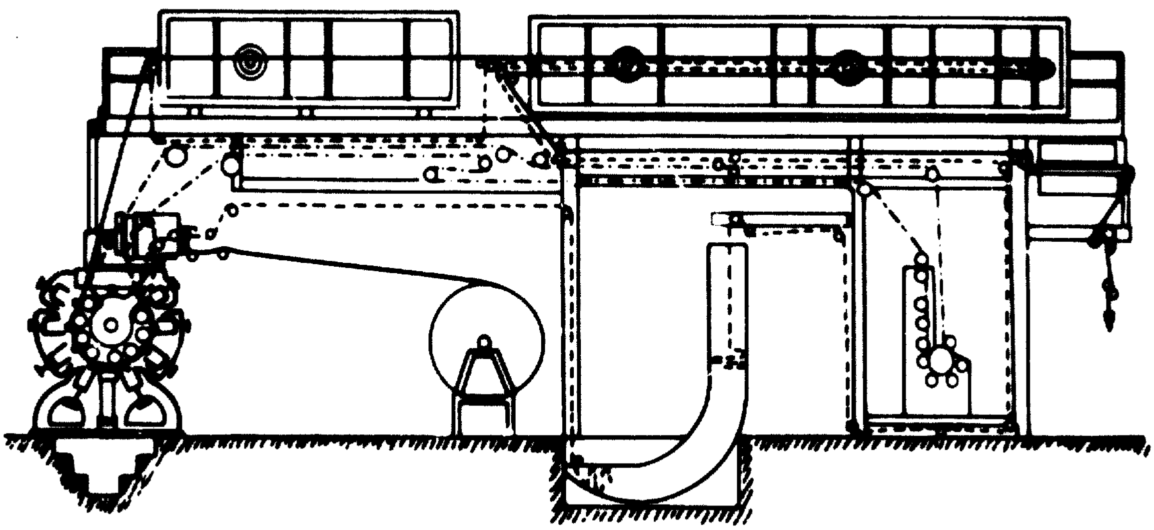

Figure 6. Artos roller-printing machine (Federal Republic of Germany) (see text)

A schematic diagram of a typical flat-screen printing machine is shown in figure 7. It is equipped with gauze screens, the non-printing portions of which are coated with paint. The printing colour, in paste form, is rubbed through the unpainted areas by a special device. The operations of printing, removal of the screen, shifting of the fabric and replacement of the screen are repeated cyclically. In figure 7, (1) is the endless printing belt, (2) the feeding device and (3) the flat screen.

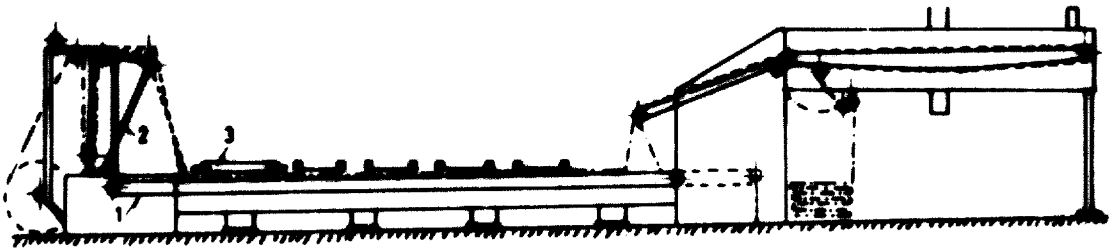

Figure 7. Buser Hydromag IIb flat-screen printing machine (Switzerland) (see text)

A very modern type of cylindrical-screen printing machine is shown schematically in figure 8. It is provided with cylindrical screens, prepared with paint in the same way as with flat screens, which rotate on the moving surface of the fabric that is being printed. The colour to be printed, also in paste form, is forced through the screen from inside the cylinder. In figure 8, (1) is the cylindrical screen, (2) the painted fabric and (3) are electromagnets.

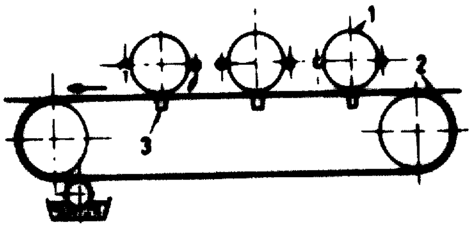

Figure 8. Zimmer cylindrical-screen printing machine (Austria) (see text)

NEW METHODS FOR DYEING AND FINISHING FABRICS MADE FROM COTTON, REGENERATED CELLULOSIC FIBRES OR THEIR BLENDS

by

J. Gajda and W. Szczepaniak

Modern bleaching machines

Woven fabrics are bleached either in rope form or in open width, depending on their weight and type. Light fabrics of a loose structure and of weights up to 120 g/m^2 are bleached continuously in rope form, but heavier fabrics of a compact structure and of weights over 120 g/m^2, as well as fabrics made from synthetic fibres, require bleaching in open width. Machines for bleaching fabrics in rope form at linear speeds up to 200 m/min consist of the three following units: a roller washing machine (figure 1), padding equipment (figure 2) and a J-box (figure 3).

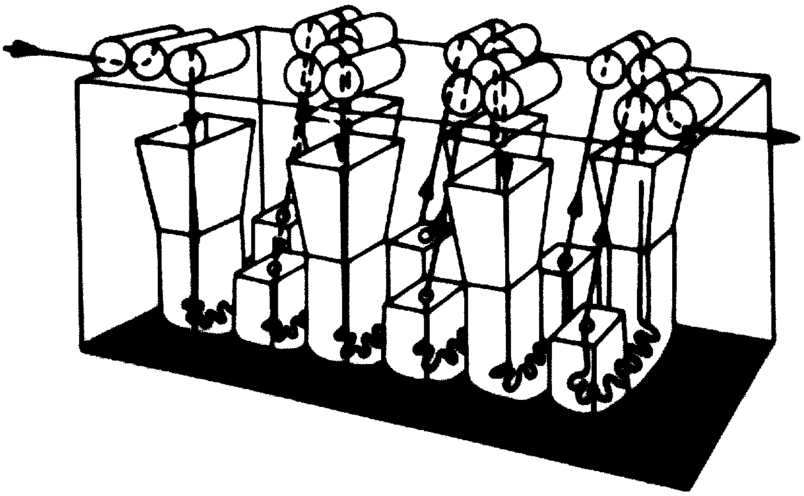

Figure 1. Roller washing machine for woven fabrics

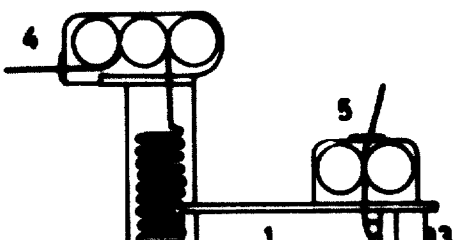

Figure 2. Padding equipment for woven fabrics: (1) padding box, (2) inlet for chemicals, (3) outlet for chemicals, (4) fabric entry, (5) fabric delivery

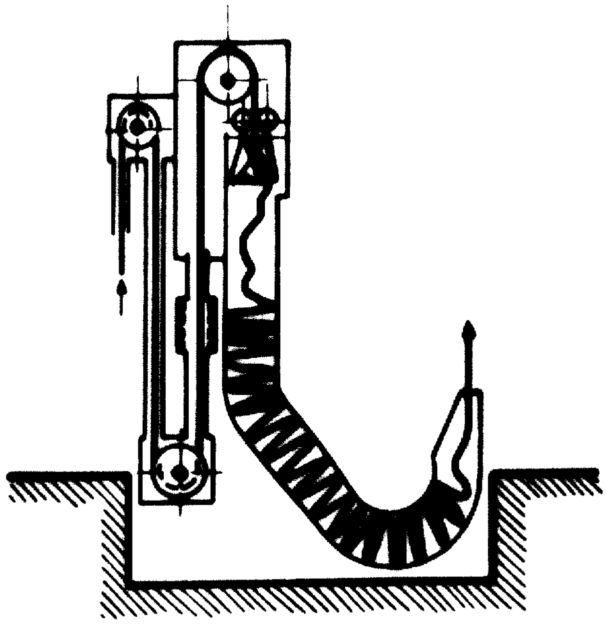

Figure 3. J-box for woven fabrics

The number of units included may differ depending on the bleaching method applied, but usually there are no more than four. The four-unit bleacher is used in the hypochlorite-peroxide method, which is believed to be the most economical. In this case, there are two J-boxes for hot processing: one for alkali kiering and one for peroxide bleaching. The other two J-boxes are used for cold processing: one for the acid wash after kiering and the other for hypochlorite bleaching. The fabric is thus subjected to the four following treatments successively: kiering, acid washing, hypochlorite bleaching, and bleaching with hydrogen peroxide. The efficiency of the plants in continuous bleaching in rope form depends upon the capacity of the J-boxes, in which the treatment time is definite and thus restricts the linear speed of the cloth through the other machines in the line.

The speed of passage of the fabric in open-width bleachers is lower, not exceeding 100 m/min. Such bleachers work in a semi-continuous way when pad-roll machines or heat chambers that are provided with devices for continuous transport (figure 4) are used.

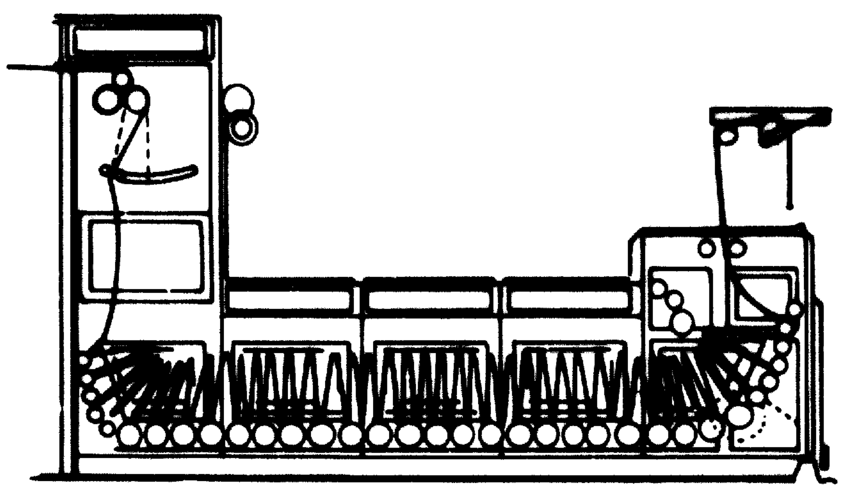

Figure 4. Heat chamber with continuous transport

The pad-roll machines have found the most extensive application. These devices, when they include an adequate number of attached reaction chambers, allow the process to be carried out in a way similar to the continuous one. Bleaching in the open-width bleachers is performed by the padding and steaming method, using either hydrogen peroxide or sodium chlorite, or by the method of combined bleaching with chlorite and peroxide. Bleaching with sodium chlorite is particularly important in the case of cloth made from synthetic fibres and their mixtures with regenerated cellulosic fibres, since other agents may either damage the fibres or fail to secure the proper degree of whiteness. Open-width bleachers with continuous transport equipment are little used because they form folds and creases that are difficult to eliminate (figure 5).

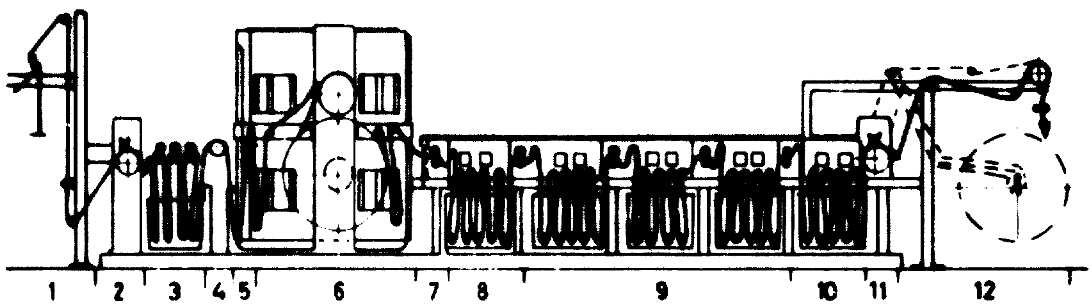

Figure 5. Open-width bleacher with chamber for fabric drying: (1) fabric entry unit, (2) driving rollers, (3) padding box, (4) squeezing rollers, (5) pre-heating zone, (6) heating chamber with rewinding device, (7) driving rollers, (8) washing box of washing machine, (9) rinsing boxes of the washing machine; (10) fabric neutralizing boxes, (11) squeezing rollers, (12) delivery unit (to rollers or carts)

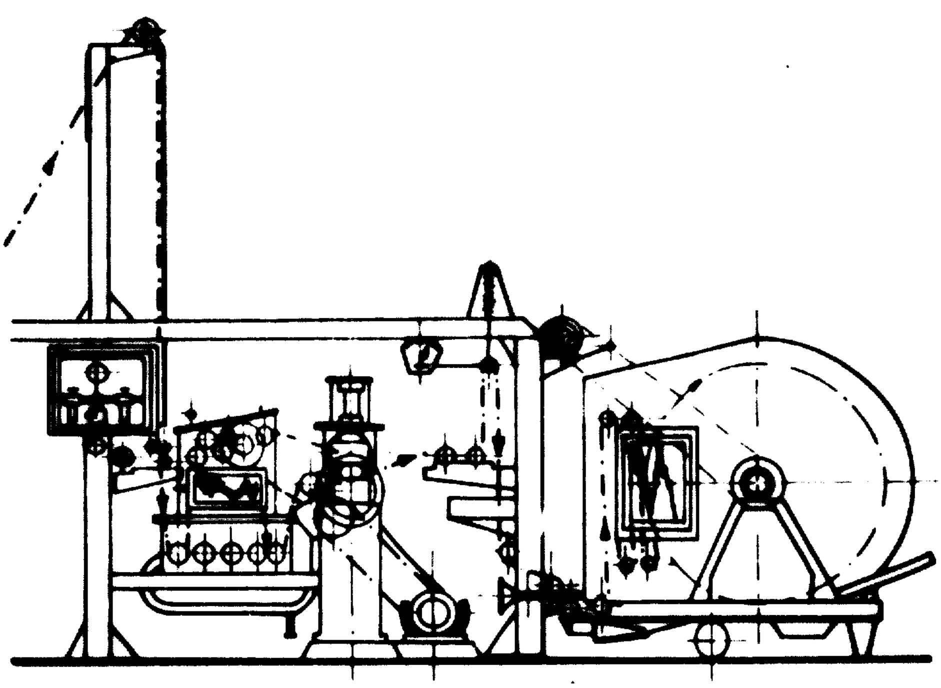

Figure 6. Pad-roll equipment for bleaching

The open-width bleacher usually consists of two units: *(a)* a continuous open-width washing machine combined with padding equipment and a feeding device at the heat chamber with continuous transport, and *(b)* a continuous washing machine. In the first unit the desized cloth is scoured, impregnated with bleaching agents and wound in the reaction chamber. In the second unit the residual chemicals and the water-soluble products of oxidation (hemicellulose, proteins, pectins, natural dyes and the like) are removed. The pad-roll machines for bleaching are of the same type as those used for dyeing by this method (figure 6).

Continuous open-width washing machines

The continuous open-width washing machines used in the cotton and silk industries are based on the design of a roll box. Because of the intensification of the washing process, a counterflow passage of the cloth is applied in the sections of the machine. This makes possible a turbulent flow of the bleach bath and at the same time increases the effectiveness of the washing process without the need to install additional mechanical elements that might slow the process (figure 7). In these machines, a cascade counterflow of the bath is generally applied, making it possible to decrease consumption of water and improve its utilization. In addition, to increase the effectiveness of rinsing and washing, spraying pipes are installed near the squeezing rollers, the latter being under high pneumatic pressure, which ensures a high degree of squeezing and, at the same time, counteracts the transfer of over-large amounts of impurities from section to section. The sections of the washing machine are covered in order to minimize heat losses and have only inlet and outlet slots. The squeeze rollers between the sections have a drive synchronized by means of compensators that operate under the influence of the alternating tension of the cloth. This ensures a minimal tension of fabrics, which is necessary for their proper passage through the machines.

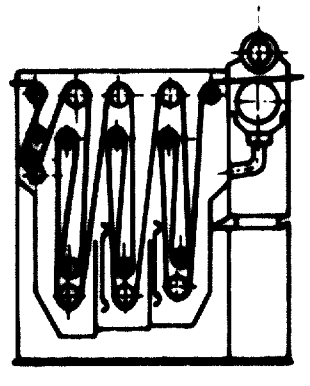

Figure 7. Open-width washing machine with counterflow

A new development for fabric rinsing in open-width is what is called the Rotowa system (figure 8). The method depends on rotating a beam of the cloth on a perforated cylinder and supplying water from inside it. This centrifuging ensures a high efficiency of the rinsing process. The application of this method is limited, however, to final rinsing, with no further treatments with chemical solutions.

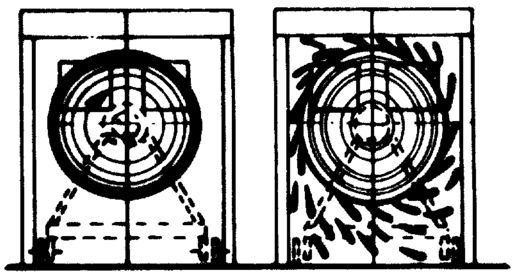

Figure 8. Heberlein "Rotowa" system washing machine (Switzerland)

Continuous and semi-continuous methods of dyeing

The basic features of the batch dyeing process are its low efficiency and difficulty in dyeing a large number of batches according to the standard. In order to eliminate these problems, continuous and semi-continuous dyeing methods have been widely introduced recently. The semi-continuous methods make possible higher efficiency and better quality of dyeing. It is also easier to obtain larger batches of uniformly dyed fabric. The efficiency of the continuous methods is much higher than that of the batch process; with them, great quantities of cloth can be dyed to the same colour and hue. These methods, however, are economical only in bulk production. Fabrics for continuous dyeing require a special structure and must be prepared very carefully.

The common feature of the continuous and semi-continuous dyeing processes is the padding of the cloth in a dyestuff solution. This operation is carried out in padding machines. The fabric is introduced into a special trough of the padding machine that contains a dyestuff solution. The excess of the dyestuff solution is removed from the fabric by squeezing between rubberized rollers under high pressure. During the padding operation itself, the dyestuff is not yet combined with the fibre. The penetration of the dye into the fibres occurs mostly at an elevated temperature within a certain period of time. After padding has been completed, the fabric should be subjected to treatments that fix the dyestuff in the fibre. If such an operation is carried out by a batch method, the process is called a semi-continuous dyeing method. The method is called continuous if dye fixation occurs during an operation carried out continuously.

Among the best known semi-continuous dyeing methods are the pad-jig and pad-roll processes, while among the continuous methods there are the pad-steam and Thermosol processes.

The pad-jig process

In this process the dyestuff introduced into the fabric during the padding operation is fixed to the fibre by means of a special developing-bath vibrating vat (jig). This method has been developed for vat dyestuffs. The cellulosic fibre fabric is padded with a dispersion of an insoluble pigment. The developing bath in the jig contains hydrosulphite, sodium hydroxide and a considerable quantity of common salt or sodium sulphate. While the fabric is drawn through this bath, the dyestuff becomes soluble and easily penetrates the fibres. After dyeing has been completed, the dyestuff is oxidized to an insoluble form within the fibre. The fabric is then washed and rinsed.

By means of the pad-jig process, fabrics made from cellulosic fibres can be dyed with soluble sulphur dyestuffs of the Hydrosol type (Federal Republic of Germany) and with the reactive, azoic, and direct dyestuffs, using developing baths appropriate to the dye used.

The pad-roll process

After being impregnated with a dyestuff solution, the fabric is heated by means of steam and infra-red radiation to a temperature just exceeding 100°C and wound up on a rotating roller in a chamber filled with steam at 105°C. About 3,000 to 5,000 metres of medium-weight cloth can be wound up in a single chamber. The fabric, in beam form, is rotated slowly for from 2 to 4 hours in the steam-filled chamber. After dyeing, the fabric is washed in the continuous washing machine.

This process is suitable for dyeing fabrics composed of cellulosic fibres with direct, reactive, and sulphur dyes, as well as for dyeing woollen fabrics with acid dyes, using special auxiliary agents that form a coacervate, that is, a system consisting of a dispersed phase rich in the auxiliary agent and the dye, and a dispersing phase lean in the dyestuff.

The pad-steam process

The universal plant for carrying out the pad-steam process consists of a padding machine, a dryer, a second padding machine, an ager and a continuous washing machine. The cloth can pass continuously through all of these units or just some of them. This process is mostly used for dyeing fabrics made from cellulosic fibres. Different dyestuffs can be used. The operations that must be carried out when dyeing with different dyestuffs are shown in table 1.

TABLE 1. SCOPE OF APPLICATION OF THE PAD-STEAM PROCESS

Dyestuff		*Padding machine*	*Dryer*	*Padding machine*	*Ager*	*Washing machine*
Direct		—	—	D	+	R
Reactive	a	D	+	F	+	R + S + R
	b	—	—	D	+	R + S + R
Sulphur		—	—	D	+	O + R + S + R
Azoic		N	+	B	—	R + S + R
Vat		D	+	F	+	O + R + S + R
Indigo-sol	a	D	+	—	+	R + S + R
	b	—	—	D	—	F + R + S + R

Key: +, operation applied; —, operation not applied; D, dyestuff; R, rinsing; F, fixation; S, soaping; O, oxidation; N, naphtol; B, base.

The thermosol process

This method is used to dye the fabrics made from polyester fibres with disperse dyestuffs or vat dyestuffs specially selected with regard to their dispersion and dyeing properties. The fabric is impregnated with a dye dispersion, dried, and heated for about 1 minute at 190 to 210°C. Under these conditions an easy and rapid diffusion of the dye into the fibres occurs, resulting in a fast dyeing.

The Thermosol process is also used in dyeing fabrics made from polyester and cellulose blends. The simultaneous dyeing by this method of the polyester component with a disperse dye and of the cellulosic component with a reactive dye is rather difficult to control. Usually, the only polyester component is dyed by the Thermosol method, the cellulose fibres being dyed afterwards either continuously or discontinuously with appropriate dyes.

Systems for preventing fabric shrinkage

Finishing for unshrinkability is based on the application of chemical finishing agents (urea melamine formaldehyde condensates), suitable mechanical devices, or both. Mechanical processing for the prevention of fabric shrinkage is limited to: *(a)* carrying out the wet processes under as little tension as possible to ensure a free relaxation of the tension accumulated during the interoperation drying process under conditions that allow the fabric to be shrunk (festoon dryers, continuous belt dryers and stenters with over-feeding) or *(b)* by the application of special machines in final operations such as the sanforizing (United States) and Monforts (Federal Republic of

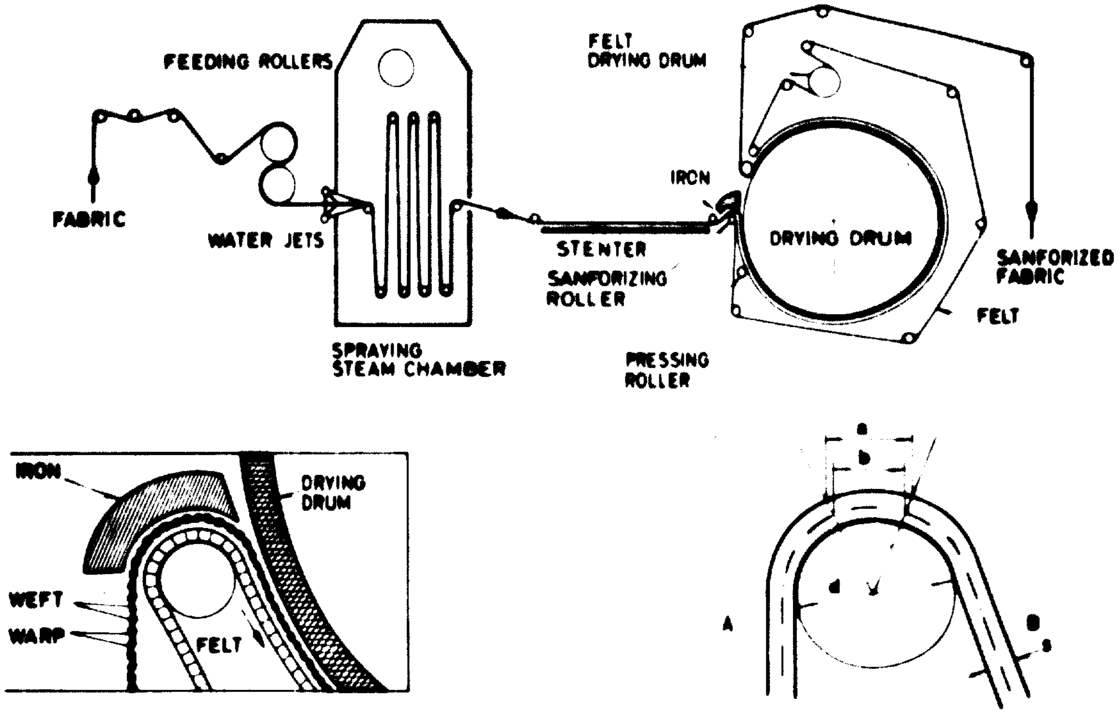

Figure 9. Sanforizing machine to prevent fabric shrinkage; detail drawing, lower right (A) felt before entering on sanforizing roller; (B) felt leaving sanforizing roller, (a) length of the external arc of the felt over the sanforizing roller, (b) length of felt section (a) when straightened, (d) diameter of the sanforizing roller, (s) thickness of the felt

Germany) process. The Montforts system consists of a blow dryer, a tensionless stentering machine of the Palmer type, and a felt calender. These plants produce a forced shrinkage of fabrics that require very low shrinkage in use. In the sanforizing machine, which is shown in figure 9, the fabric is subjected to wetting in a steam-spraying chamber in order to swell the fibres and the finish. The stressed yarns of the weft then shrink in the stentering machine and contribute to a higher degree of braiding the weft by the warp.

When passing over the sanforizing roller, the warp is subjected to a compressive shrinkage that is stabilized during drying over a felt-covered drum. The shrinkage of the sanforized fabric should not exceed 1 to 1.5 per cent. The sanforizing effect depends on the proper selection of the diameter of the sanforizing roller and on the thickness of the felt and fabric. These factors have a definite mathematical relationship.

The assemblies for the Monforts process, because of the action of a felt calender similar to that of a decating machine, confer on the fabric a soft and full feel. This type of assembly is particularly suitable for fabrics made from viscose staple fibres. In this case the shrinking effect is not obtained in a single process, as in the sanforizing method, but during a series of operations. For this purpose, the assembly includes tensionless blowing dryers and stentering machines. Finally, the fabric passes through the felt calender, which differs from the sanforizing machine in having no electric irons. The output of Monforts assembly is from 11 to 45 m/min.

In modern technology, plants for mechanical shrinking are used for fabrics with particularly high requirements as regards resistance to shrinkage.

NEW DYEING AND FINISHING METHODS FOR WOOLLEN AND WOOLLEN-TYPE FABRICS

by

H. Jędraszczyk and H. Cichowski

A production process of the modern type is characterized by high quality of products, low manufacturing cost and a minimal input of labour. In the woollen industry, finishing, in its traditional form, is based mainly on operations of very low productivity. This is justified by the high price of wool and, on the other hand, by the specific properties of wool fibres, which require what are called periods of interoperation rest.

Although the finisher in the wool industry can carry out almost all processes continuously, except milling, it is, however, very difficult to introduce such systems into industrial practice. The bulk production of blended fabrics of the woollen type that contain high proportions of man-made fibres has made it possible to introduce continuous finishing systems.

Uniformity of the product assortment in the finishing department is of the greatest importance if continuous finishing is to be economical and profitable and to continue to be an important factor in modern production systems. The hitherto prevailing practice of using commission finishers, popular mostly in Central Europe and the United Kingdom, has led to the belief that a wool finishing department should be able to deal with all types of fabrics. This belief was supported by the fact that, with other methods of finishing, the periods of interoperation rest were long and at the same time the machines used were old and inefficient. Modern methods of continuous finishing impose quite different demands on production programming, and this fact has significantly changed the character of the finishing department in a textile unit.

A rapid development of finishing-machine construction and of new technologies has resulted in a situation in which finishing-service plants of the traditional type cannot compete with specialized finishing works. It is impossible to utilize profitably the power output to the machines in universal finishing plants, since the labour factor is very high. Consequently, either semi-continuous or continuous systems have been introduced increasingly during the last few years for certain operations or even to the entire finishing process.

However, these systems have developed rather slowly in the woollen industry, the main difficulties being the old and cramped nature of existing buildings, the high prices of finishing machines and the anxiety of managers concerning the possibility that a failure in a single machine in the continuous line could cause stoppage of the entire production process.

Preparatory processes

In this field the carbonizing equipment for removing burrs from woollen fabrics belong to the continuous units that were introduced very early. The carbonizing unit consists of a vat for steeping the fabrics in a solution of sulphuric acid, a suction machine or squeezer, and a two-stage heating assembly (dryer and oven), all of the machines being in a single line. Some assemblies of this kind have been in operation for more than 25 years.

The most important preparatory process is scouring. Here, the continuous system for wool fabrics was not developed until the last few years. Among the most important designs are the three following:

(a) The rope scouring machine of Hunter (United States), now in operation in a continuous line in Kalinin (Soviet Union). This machine is diagrammed in figure 1.

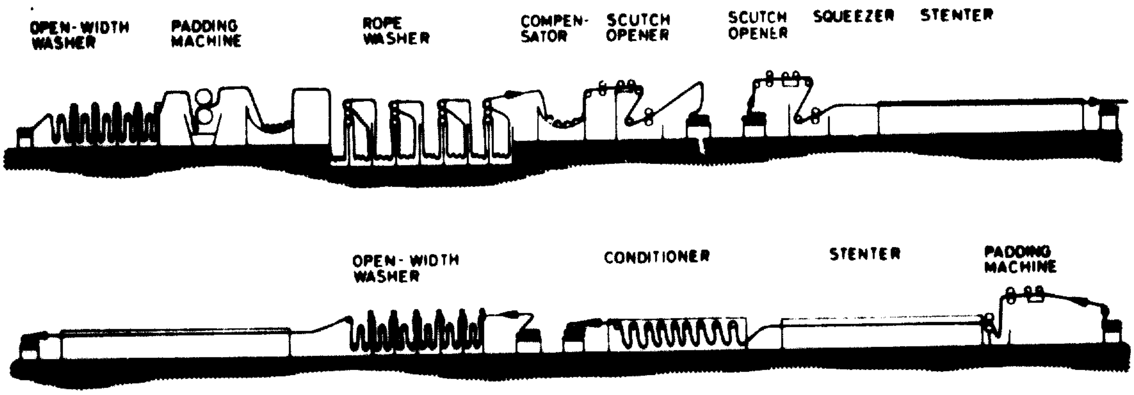

Figure 1. American (Hunter) rope scouring machine (in operation in Kalinin, Soviet Union)

(b) Open-width scouring machines of various types designed by various producers in the Federal Republic of Germany (Schiffers, Hennecke, Hemmer). Two of these are diagrammed in figures 2 and 3.

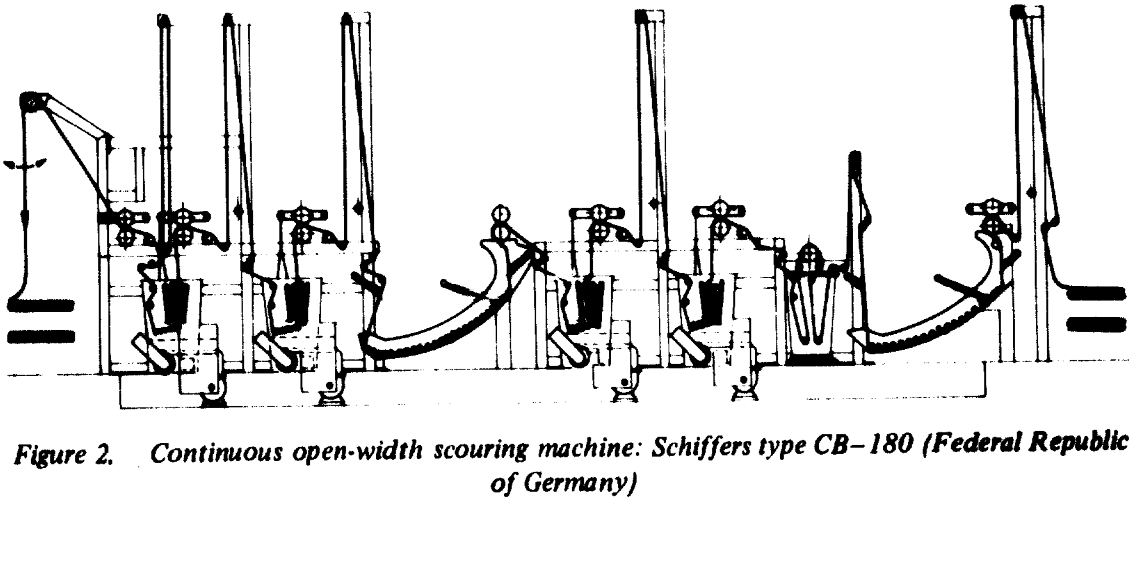

Figure 2. Continuous open-width scouring machine: Schiffers type CB–180 (Federal Republic of Germany)

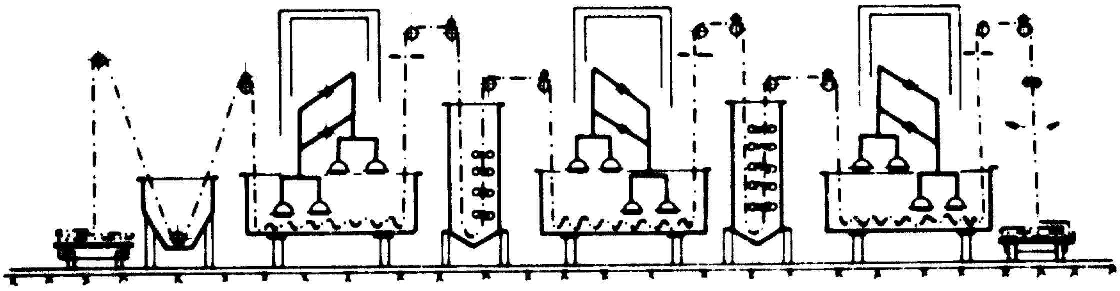

Figure 3. Continuous open-width plunge-bell washer (Federal Republic of Germany)

(c) The open-width scouring machine, made in Poland, consisting of padding and rinsing vats (type BU-5), scouring vats supplied with a special pressing device (BU-13), and squeezers (EH-13). This assembly can be set in long lines together with other machines as shown in figure 4.

The continuous-line machine set shown in figure 4 consists of the following elements:

Section I (washing and drying):

(1) Feeding-in equipment from a warp beam or a truck;
(2) Padding bowl for impregnating raw fabrics with detergent solutions;
(3) Squeezer for removing excess detergent solution;
(4) Compensator in which fabrics remain for 1 to 10 minutes, soaking up the detergent solution;
(5,7,9) Detergent bowls with special equipment for intensification of the scouring effect;
(6,8,10) Squeezers (EH-13);
(11) Compensator for extending the action time of detergent solutions;
(12,14) Rinsing bowls with 3 sprays and 5 pairs of feeding-squeezing rollers for rinsing fabrics with hot and cold water;
(13,15) Squeezers;
(16) Perforated drum drier;
(17) Winding device.

Section II (padding and drying)

(18) Feeding equipment;
(19) Padders for padding with dyes or finishing resin solutions;[1]
(20) Hot-flue drier;[1]
(21) Second padder for padding with finishing resins;[1]
(22) Stenter with thermofixing fields;
(23) Winding-folding machine;
(24) Conveyor belt for carrying fabric and ensuring periods adequate for full cross-linking of finishing resins.

Section III (rinsing and drying)

(25) Feeding equipment;
(26 37) Complex washer with 6 washing-rinsing vats (BU-5) and 6 squeezers (EH-13);
(38) Intermediate compensator;
(39) Drawing-intake equipment;
(40) Five-passage stenter;[1]

[1] Equipment imported and adapted for use for duty in a continuous line.

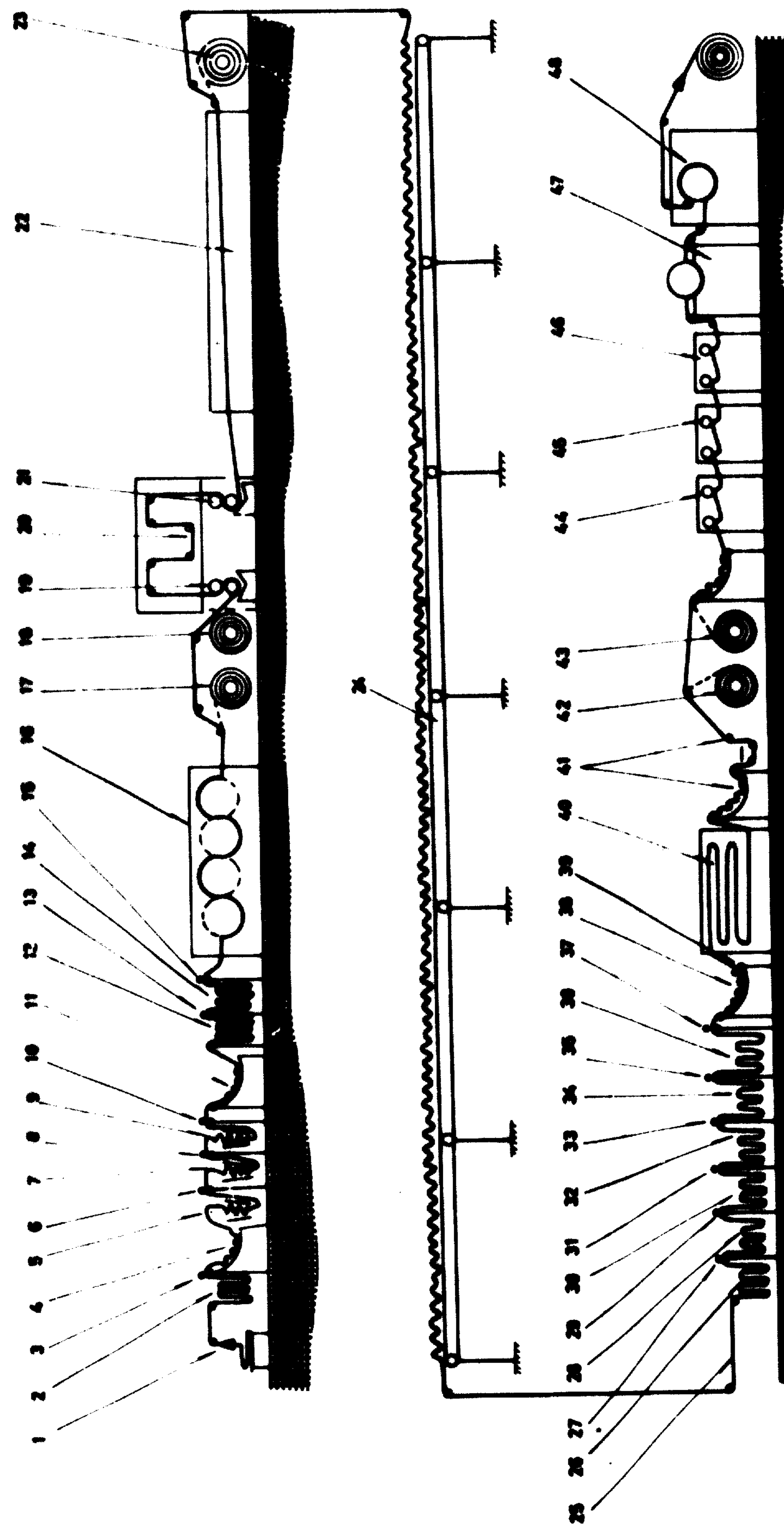

Figure 4. Polish-made continuous open-width scouring machine (see text)

(41) Cloth-inspecting board;
(42) Winding-folding machine.

Section IV (final dry finishing)

(43) Feeding equipment;[1]
(44) Two-cylinder shearing machine (Crosta, Italy) for shearing the upper surface of fabrics, with turning-over devices;[1]
(45,46) Two 2-cylinder shearing machines (Crosta) for shearing the upper surface of fabric;[1]
(47) Cylinder press with steam equipment (Crosta);[1]
(48) Continuous decatizing machine (produced by Sperotto, Italy) for final fabrics dressing.[1]

Like scouring and carbonization, crabbing is one of the preparatory processes. Special machines have been built recently for this purpose, allowing the process to be carried out in a continuous way. The arrangement of such a machine is shown in figure 5.

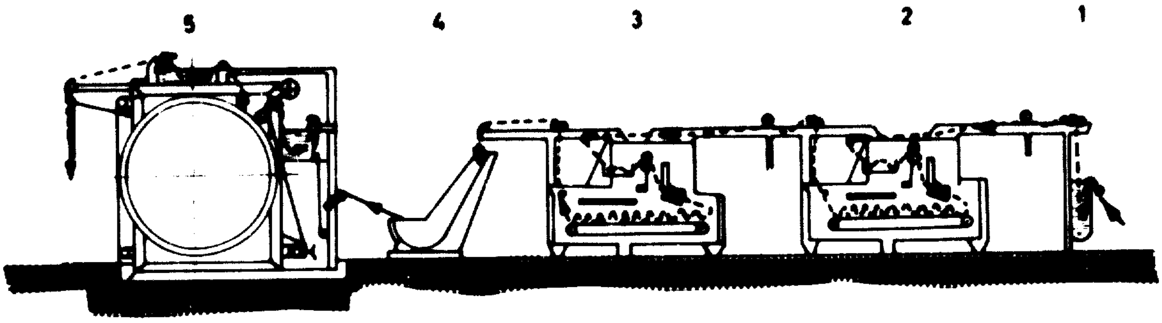

Figure 5. Continuous range for washing and crabbing: (1) impregnation box, (2) and (3) scouring machines, (4) compensator, (5) continuous crabbing machine

Fabric dyeing

Fabric dyeing in the wool industry is traditionally done in the batch process, carried out in winch dyeing machines. Recently, there has been introduced a process for the continuous dyeing, by the so-called Thermosol method, of fabrics that contain polyester and triacetate fibres. The method depends on padding the fabrics with a dye solution in a padding machine, drying them, reheating them at an elevated temperature (about 200°C) for about 1 minute, and final scouring. This method is used mostly for dyeing mixtures of polyester and cellulose fibres as well as the polyester components of wool blends. The arrangement of machine units for dyeing by this method is shown in figure 4 (19–22). More details about the Thermosol methods are discussed elsewhere in this publication.[2]

A very recent development for dyeing in the wool industry is the pad-roll method, which consists of padding the fabric with a dye solution and then drying and steaming it in the form of a beam. It can be used for dyeing all types of woollen fabrics and blends of wool with various man-made fibres. The method can be

[1] Equipment imported and adapted for use for duty in a continuous line.

[2] J. Gajda and W. Szczepaniak "New methods for dyeing and finishing fabrics made from cotton, regenerated cellulosic fibres or their blends", pp. 13–20, this volume.

considered as the one best suited for the woollen industry, since it is universal, highly efficient and permits the dyeing of small batches of fabrics in different colours.

The winch and batch dyeing machines, as well as high-pressure beam dyeing machines, because of their low efficiency, will be used mostly as a production reserve for the correction of misdyeing and for dyeing exceptionally small batches or single pieces.

The yield coefficients per worker calculated with the Thermosol method (single bath) are sixfold greater than those obtainable with the winch dyeing process and tenfold greater than with the pad-roll method. The yield indices based on the manufacturing area unit are increased in the case of the Thermosol and pad-roll methods by 50 per cent and 150 per cent respectively.

New techniques of fabric finishing

Except for the work being done in the chemical industry, the following can be classified as the principal modern trends in fabric finishing:

(a) Introduction of the "wet-to-wet" system of padding, which depends on the treatment of wet fabrics (after squeezing) with concentrated solutions of finishing resins. Such a method eliminates the necessity for double drying and makes it possible to impregnate the fabrics with waterproofing, mothproofing, antistatic and softening agents.

(b) Introduction of the spray system for coating with finishing agents. This method (Polish Patent No. 53353) permits the application of the "wet-to-wet" process and coating of the fabric successively with various finishing agents.

Fabric dry finish

The dry finishing of woollen type fabrics include many operations, the most important of them being: shearing, steaming, ironing and decatizing. In general, except for the decatizing machines and hydraulic presses, all operations are always carried out in a continuous way from one trolley to another. Recently, there have appeared also decatizing machines working in a continuous manner, for instance those of Sperotto (Italy). One such machine is diagrammed in figure 6. It will therefore be possible to set up a continuous line for the final dry finishing of fabrics. An example of such a line is shown in figure 4 (43 48), based on the Italian machines.

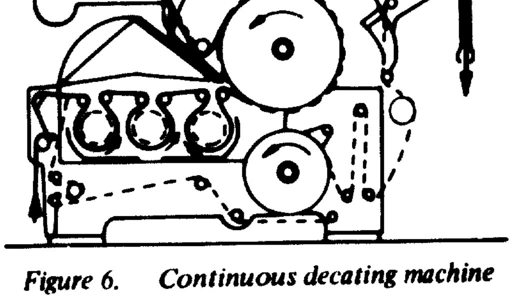

Figure 6. Continuous decating machine

Technical and organizational problems

The preparation of fabrics for modern continuous finishing requires special work organization. Colour-woven fabrics should be prepared in batches that are uniform in width and similar in weight per square metre and in raw material composition. If these conditions are not fulfilled, difficulties will occur during drying, and a change of the dryer speed will be necessary, which is undesirable during scouring, heat-setting and other operations. The larger the batch of uniform fabric, the easier and more economical the process becomes.

When introducing continuous systems, one of the fundamental conditions for correct operation is the standardization of raw fabrics. All incidental errors such as staining, weaving errors and the like must be overcome where they originate.

The semi-continuous and continuous wet processes are carried out in machines provided with devices for automatic feeding with chemicals. For this purpose, all chemical agents supplied to the finishing department should have always the same properties. This is particularly important in dyeing, where any change during the work is undesirable. As a result, the importance of the system of testing the auxiliary agents and dyestuffs in the plant has grown considerably.

On the basis of the data presented above and papers that have appeared recently in various technical journals, the four following conclusions can be drawn:

(a) Almost all of the more important finishing machine manufacturers for the woollen industry are developing new designs for semi-continuous or continuous processing systems. The most rapid progress may be observed in the field of the open-width scouring machines and continuous lines for dry finishing.

(b) The pad-roll method seems to be the best technique for dyeing because of its high efficiency and the possibility of making frequent changes of colours.

(c) In woollen-type fabric production of about 5 million metres per year, particularly in the case of polyester-rayon blends of similar kinds, it is advisable to build full continuous lines similar to the one built in Poland that has been discussed.

(d) It is clear, according to expert opinion in Poland and elsewhere, that woollen-type fabrics finished by the continuous method are not of a lower quality than those finished by the batch technique; on the contrary, the reproducibility of the desired effects is considerably better. In the case of dyeing, however, it is necessary to prepare the dye recipe very carefully as well as to perform a test dyeing under controlled conditions, because there is no possibility of improving the dyeing effect during the course of the process.

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HIGH-TEMPERATURE DYEING

by

M. Okoniewski

In recent years there has been a considerable increase in the production of hydrophobic synthetic fibres. This increase has brought a need for new dyeing techniques that require high temperatures, that is, above 100°C.

One of the most popular methods of high-temperature dyeing, used for various synthetic fibres and their blends with natural fibres, is the so-called high-temperature (HT) method. The conventional HT method consists in dyeing the fibres in an autoclave provided with a circulation system for the dye-bath (Kater, 1963).

This method is most widely used for dyeing polyester fibres, which have a very compact structure that can be loosened considerably at a temperature of about 130°C. These fibres are usually dyed with disperse dyes which, from the chemical standpoint, belong to the azo and anthraquinone dye groups, and are slightly soluble in water, i.e. several milligrams per litre (Carbonell, 1962; Meunier, lannarone and Wygand, 1963). This poor solubility and the very small size of the dye particles facilitate high dispersion.

An important part in dyeing with disperse dyes is played by the dispersing agents, which maintain the dye molecules in the dye-bath in a colloidal dispersion, thus preventing their agglomeration.

The process for dyeing polyester and other hydrophobic fibres with disperse dyes is shown schematically in figure 1.

As already noted, the solubility of disperse dyes in the dye-bath is very low, although it is necessary for the dye to diffuse in the bath and be absorbed by the fibres. Good solubility facilitates the migration of the dyes in the bath; this is essential for uniform dyeing.

However, if solubility is too high, there is a shift of equilibrium of dye distribution between the bath and the fibre towards an increase of the dye content in the bath, causing an increase in dye consumption, making intensive dyeing impossible (Carbonell, 1962).

The adsorption of dye by the fibre surface is controlled by diffusion in both the bath and the fibre. The last stage, that is, the diffusion of dye into the fibre (Carbonell, 1962), is decisive for the dyeing rate.

The molecules of disperse dye in an aqueous bath are shown in figure 2 (Meunier, lannarone and Wygand, 1963). Figure 3 represents the process of dissolution of single dye molecules in water and their diffusion into the fibre (Meunier, Iannarone and Wygand, 1963). The positions of molecules of disperse dyes in relation to the structures of polyester and acetate fibre chains are shown in figure 4 and figure 5, respectively.

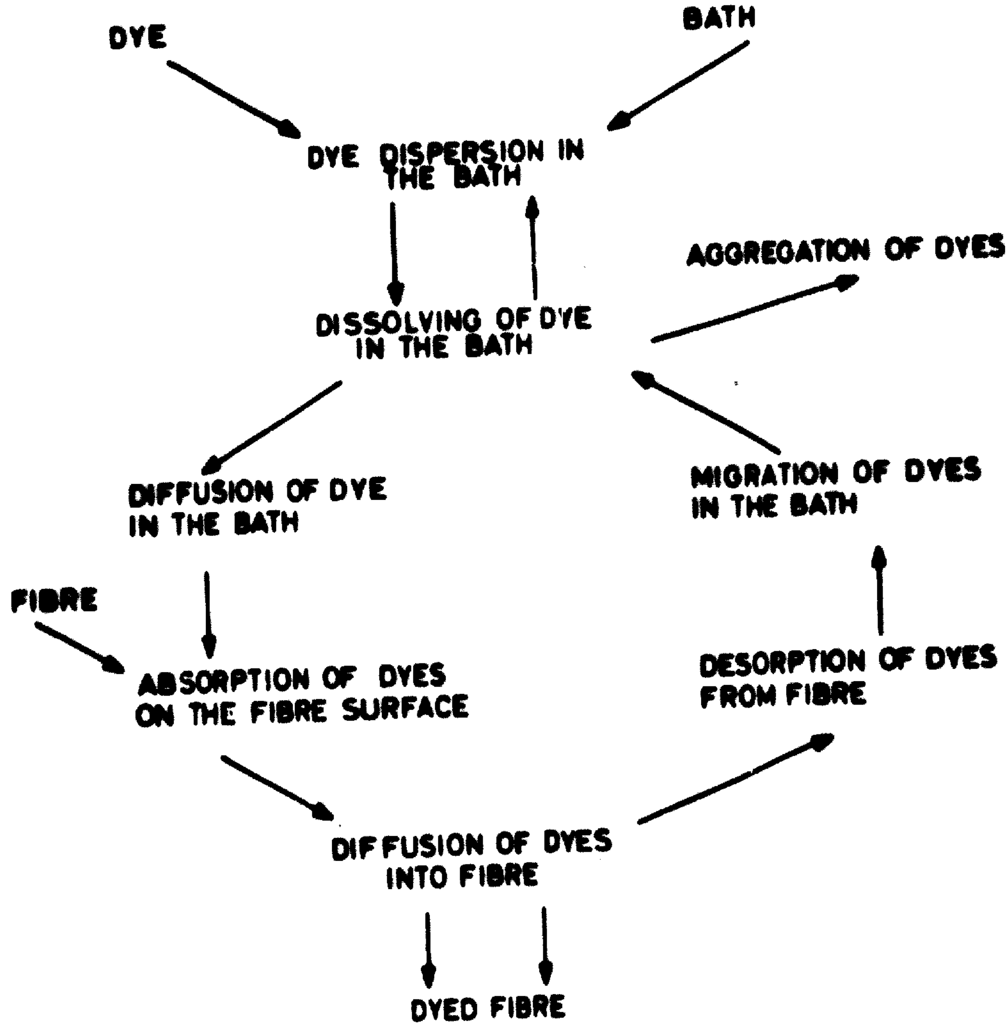

Figure 1. Schematic representation of the dyeing of hydrophobic fibres with disperse dyes (source: Carbonell, 1962)

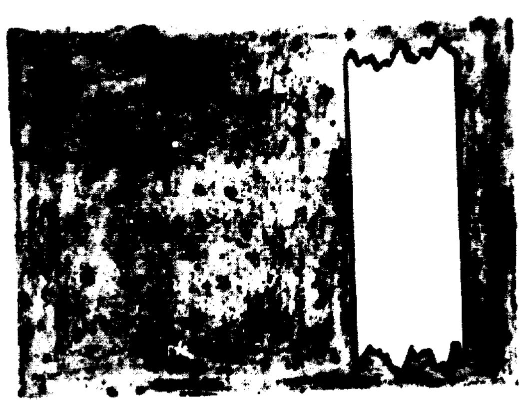

Figure 2. Fibre in disperse dye-bath (source: Meunier, Iannarone and Wygand. 1963)

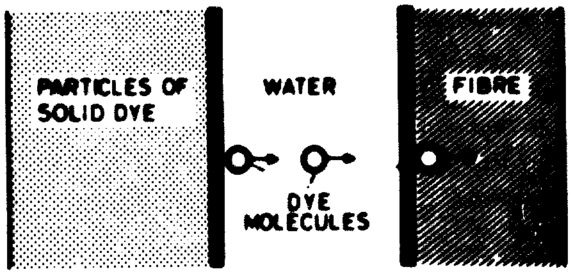

Figure 3. Mechanism of dyeing with a disperse dye

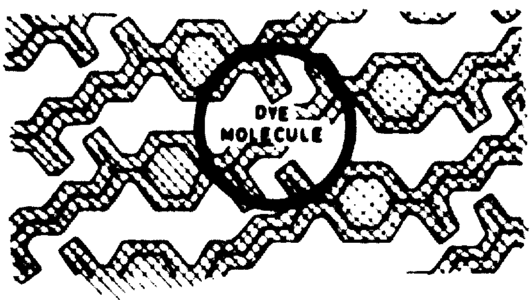

Figure 4. Dacron polyester fibre chains and dye molecule

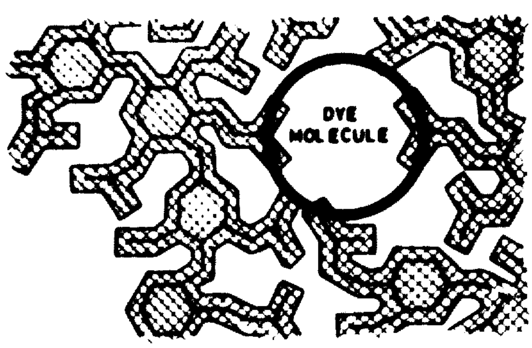

Figure 5. Acetate fibre chains and dye molecule

As can be seen from these figures, polyester fibres have much more compact structures than acetate fibres. The structure of a polyester fibre should therefore undergo a considerable loosening during dyeing to make it possible for the dye molecules to diffuse into the fibre.

An increase in the permeability of polyester fibre to dyes can be obtained not only by means of the HT method, but also by using carriers at temperatures below 100°C or by using the Thermosol method.

The use of carriers for dyeing polyester fibres is limited by the toxic properties of most carriers, their volatility in steam and their detrimental effect on light-fastness.

The HT method is used not only for dyeing polyester fibres but also for dyeing polyamide fibres (using disperse, acid, and metallized dyes), polyacrylonitrile fibres (with basic and metallized dyes) and their blends with natural fibres.

The most important advantage of the HT method is its ability to increase the diffusion coefficient of dye to fibre under the influence of elevated temperature. Because of this, the time required for dyeing can be shortened considerably, and uniform dyeing is made possible. In dyeing polyamide fibres, the streakiness that usually occurs on fabrics made from them can be notably reduced by the use of the HT method. Particularly good results can be obtained if appropriate auxiliary agents and levelling dyes are used.

The HT method has the following requirements and limitations: *(a)* Only dyes and auxiliary agents that are resistant to the effects of high temperature may be used. *(b)* The water used for preparing the dye-bath should not contain calcium and iron salts, because most of the dyes used in this process are susceptible to their action at elevated temperatures. *(c)* High temperature has an adverse effect on some textile fibres. Wool fibres undergo degradation. Some synthetic fibres, despite their resistance to heat, can be decomposed in an aqueous medium by some agents; for example, residual air in the dyeing apparatus can have an adverse effect on polyamide fibres. Polyester fibres are not susceptible to oxidation, but they do undergo hydrolysis in slightly alkaline media, so the dyeing process for these fibres should be carried out at a pH value of about 6.5 (Guyonnet, 1963).

Three types of machines are used for dyeing by the HT method: *(a)* those for loose stock, tops, tow, yarn and the like; *(b)* those for woven and knitted fabrics; and *(c)* those for full-fashioned knitted fabrics.

An example of the dyeing machines of the first group is the BA-5 apparatus, which was designed and built in Poland. Almost all of the dyeing processes in this type of apparatus are carried out at temperatures from 120° to 130°C, which corresponds to a saturated steam pressure of 1 to 1.8 atm. However, this heat is not high enough to obtain the pressure required. Since the fibre in the apparatus resists the bath flow, forced circulation by pumping is needed.

Some relative negative pressure may occur on the suction side of the pump, causing a sudden evaporation of the dye-bath. This would impede the dyeing process because the decrease in the pump delivery would cause uneven dyeing of the fibre (Jasiak, 1967).

Another harmful phenomenon is cavitation, which is the occurrence of steam or gas spaces in the flowing bath caused by the local pressure drop. Cavitation can cause the destruction of some structural components of the pump on the suction side and of the whole apparatus. Welded seams are especially vulnerable.

To prevent these deleterious effects, some preliminary pressure is applied, either by means of compressed air or by the use of a pump with a low delivery rate and high pressure (Jasiak, 1967).

In the Polish BA-5 dyeing apparatus, pneumatic pressure is presently applied; hydraulic pressure will be used in future constructions. The magnitude of the preliminary pressure required depends on the pressure drop affected by the resistance of the fibres. In the BA-5 apparatus there is a relative negative pressure of 0.3 to 0.9 atm on the suction side. A pressure of 2.8 atm would be enough to prevent the evaporation of the bath here, but for full protection against the cavitation effect, a pressure of 4 to 4.2 atm is recommended at a temperature of 130°C.

Figure 6 shows the general arrangement of the BA-5 apparatus, and figure 7 diagrams its control panel.

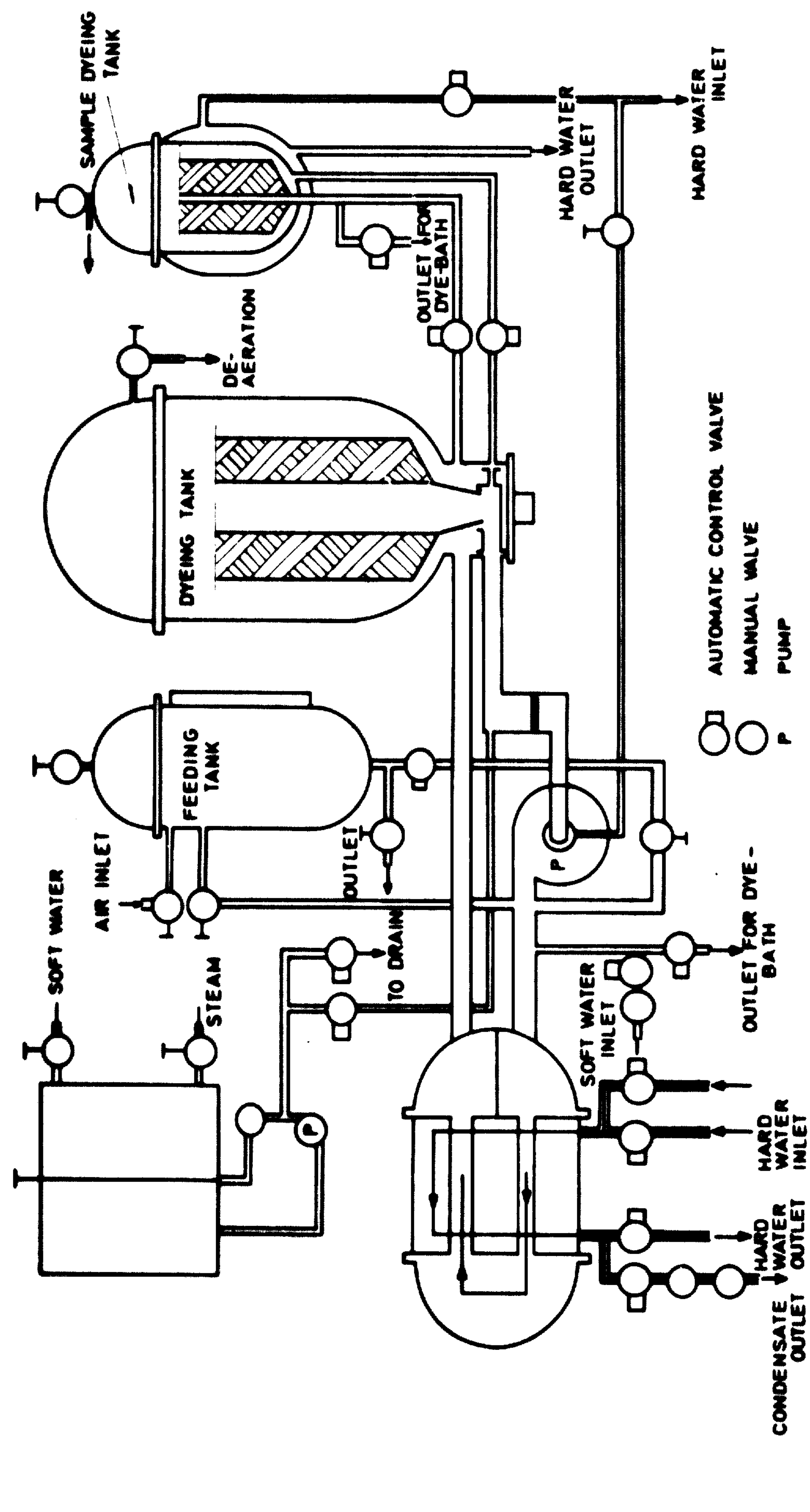

Figure 6. General arrangement of the Polish BA–5 high-temperature dyeing apparatus

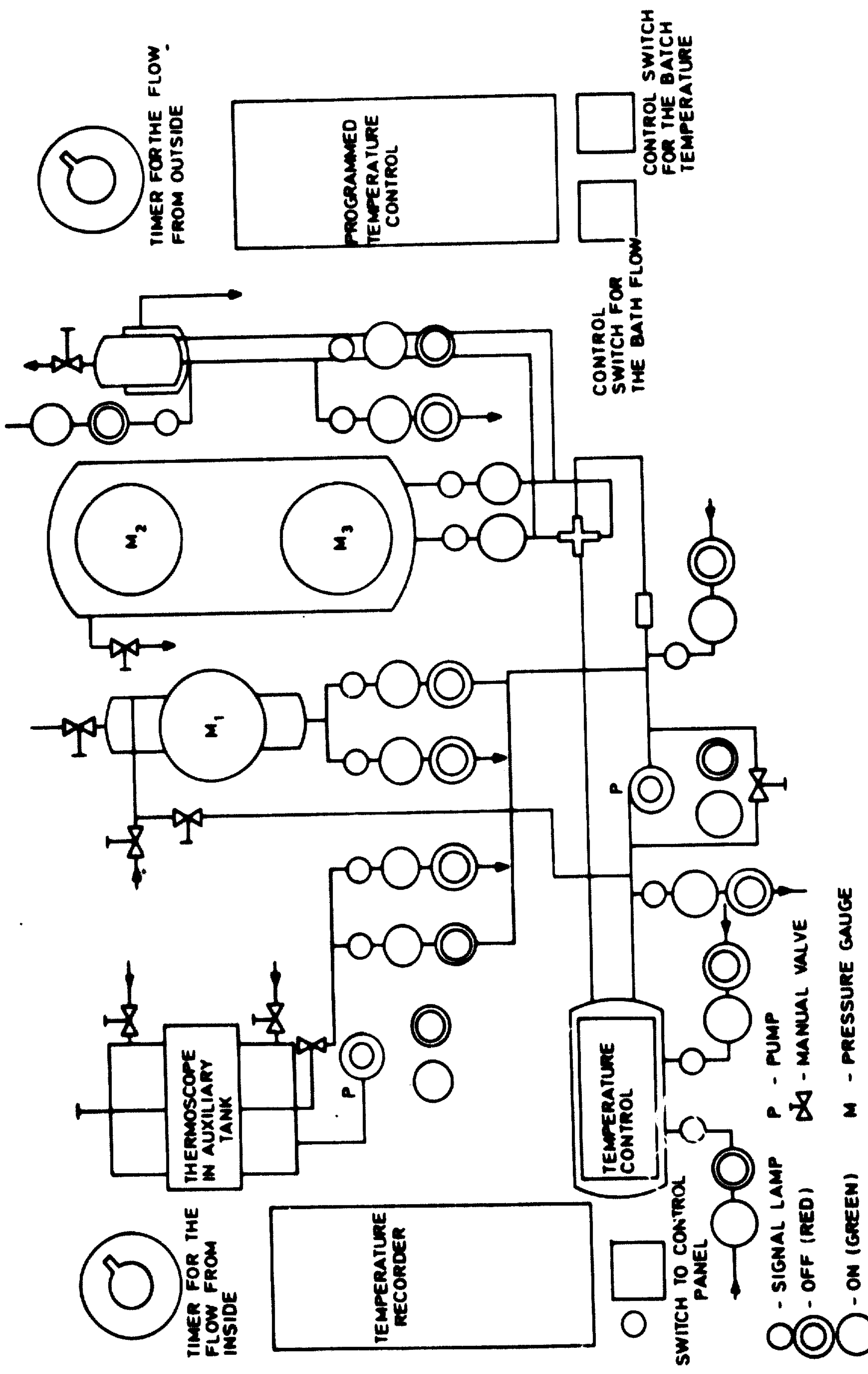

Figure 7. Diagram of the control panel of the BA–5 high-temperature dyeing apparatus

High-temperature dyeing equipment of similar construction is built by several firms, among them Henriksen (Denmark), Ilma (Italy) and Scholl (Switzerland).

At an exhibition of textile machinery in Basel, Switzerland (ITMA 1967), the Belgian machine-builder Callebaut - de Blicquy presented its new quick-dyeing equipment. This apparatus is provided with a new type of helicoidal pump. With the use of this pump and a special arrangement of the heating elements, the time required for dyeing can be shortened to only one-eight of that for dyeing with conventional equipment. Thus far, however, only a few prototypes of this equipment have been built (ITMA 1967; Callebaut - de Blicquy).

Some kinds of machines can be used for dyeing both woven and knitted fabrics. Among them are beam dyeing machines, high-pressure jigs, high-temperature winch dyeing machines and high-temperature continuous agers.

Beam dyeing machines are used primarily for knitted fabrics, but they can also be used for many woven ones. One such machine is the TSP type Ilma beam dyeing apparatus, a schematic diagram of which is presented in figure 8. Its components are as follows: (1) pressure tank, (2) cylinder, (3) beam of fabric that is being dyed, (4) four-way valve, (5) heat exchanger, (6) circulation pump, (7) static pressure pump, (8) expansion tank, (9) overflow pipe, (10) cooling coil, (11) sluice for dye-bath sampling under pressure, (12) throttling gate, (13) drain valve, (14) auxiliary connector in the suction conduit of the pump, (15) safety valve to maintain constant pressure, (16) cooling water inlet, (17) drain for condensate, (18) steam inlet, (19) cooling water outlet, (20) static pressure, (21) static pressure plus pump pressure, (22) atmospheric pressure, (23) cooling water inlet, and (24) cooling water outlet.

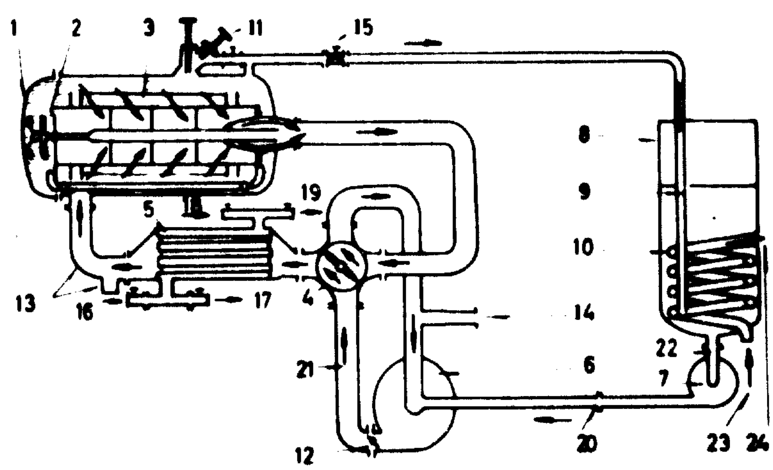

Figure 8. Schematic diagram of the TSP type Ilma beam dyeing apparatus

High-pressure jigs are used primarily to dye heavy fabrics made from synthetic fibres, either alone or blended with natural or regenerated cellulose fibres. One such machine, the Swiss Benninger HT jig, is shown in figure 9.

High-temperature winch dyeing machines are of increasing importance because of the development of knitted fabrics made from textured synthetic yarns (Callebaut-de Blicquy). One such machine, the Japanese Hisaka apparatus, is shown in figure 10.

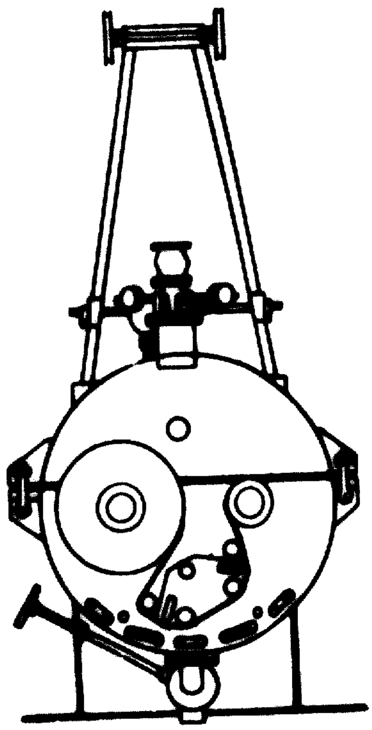

Figure 9. Benninger HT jig

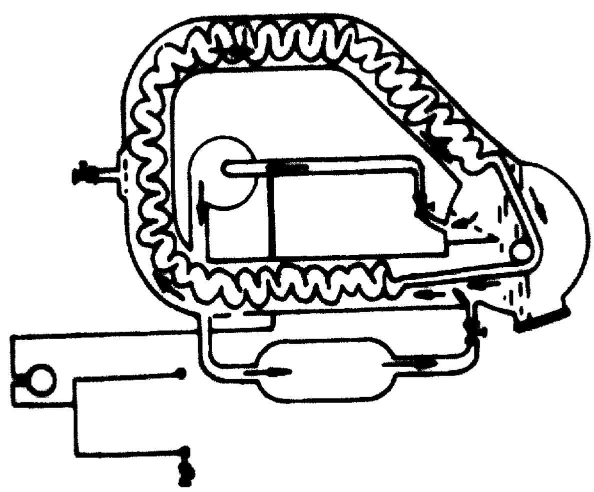

Figure 10. Hisaka high-temperature winch dyeing machine

Recent trends in the development of continuous technical processes have made it possible to introduce high-pressure continuous agers into the textile industry. With this equipment it is now possible to achieve better handle of the fabric, very good dye penetration, short duration of steaming and dyeing in open width.

In the case of the ager made in Switzerland by Peter (figure 11), it is possible to achieve a delivery speed of the dyed fabric of 25 m/min, at 130°C (Gygax, Haelters and Stein, 1966). High-temperature continuous agers are also made by Kleinewefers and by Benteler in the Federal Republic of Germany and by Hunter in the United Kingdom (ITMA, 1967; CIBA; Gygax, Haelters and Stein, 1966).

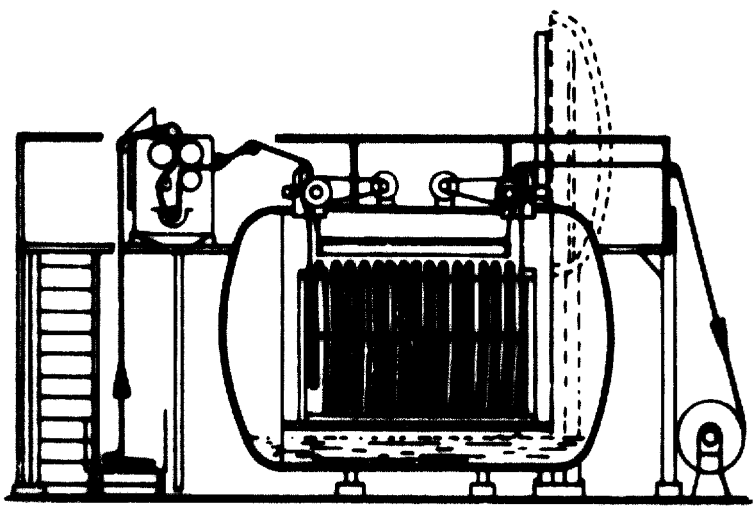

Figure 11. Peter high-temperature continuous ager

Equipment for dyeing made-up textile products by the HT method is manufactured by several firms, among them THEN (HT Paddel-Färbeapparat) and Bellman (Collorplast 65) for dyeing stockings, both in the Federal Republic of Germany.

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DURABLE FINISHES

by

H. Cichowski

In keeping with present requirements of the consumer of textiles, finishing operations must be directed not only at a higher commercial value of the processed material, but above all its wearing properties, which must be suitable for its end-use.

Recently, two basic trends to meet ever-growing aesthetic and wearing requirements demanded of the textile industry are observable. The first is the selection of suitable fibres and fabric-processing techniques, and the second concerns permanent chemical finishes to achieve desired effects. It is evident that if prevailing economic conditions do not permit a free choice of fibres, especially synthetic fibres, the only solution is to apply suitable finishing techniques. In practice, however, a middle way is chosen, and fabrics are produced from blends of natural and synthetic fibres, with or without the application of complementary chemical finishing processes.

From the consumers' point of view, the ideal apparel fabric for general end-use should be crease-resistant, water-repellent, resistant to soiling and oil-staining, shrink-resistant, easy to maintain, resistant to moths, and so forth. Moreover (and this is particularly important with synthetics) fabrics should be protected against the

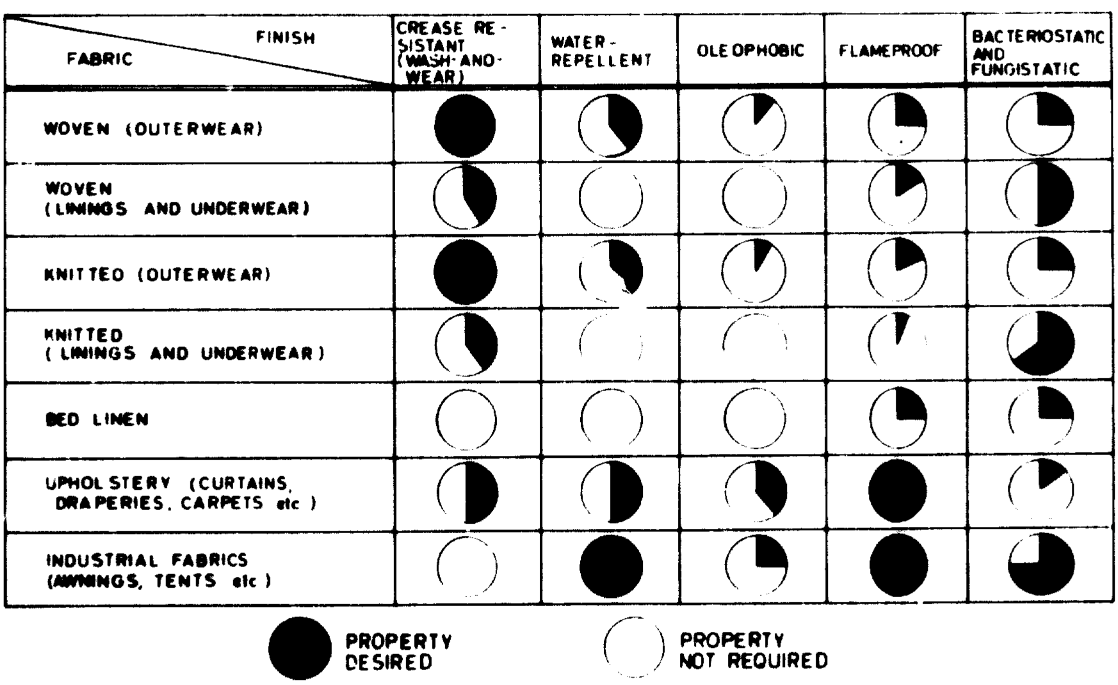

Figure 1. Desired finishes of fabrics for particular end-uses

accumulation of static electricity and be bacteriostatic. Garments made from such fabrics would provide full comfort and would be characterized by "easy-care" or "wash-and-wear" properties. Moreover, according to their end-uses, some fabrics must have special characteristics, such as resistance to heat and/or flame. The diversity and range of requirements concerning numerous groups of textiles, with regard to their wearing properties and kinds of finish, are schematically presented in figure 1.

Present levels of finishing technology, as regards available chemicals and technical equipment, permit the fulfilment of almost all requirements of consumers. As the most important and most generally applied permanent finishes in textile industry, the following may be listed.

(a) Crease-resistant finishes;
(b) Water-repellent finishes;
(c) Flameproofing;
(d) Mothproofing;
(e) Anti-static finishes; and
(f) Bacteriostatic or hygienic **finishes.**

Crease-resistant finishes

If the properties in question comprise resistance to creasing and shrinking, as well as the wash-and-wear feature, the increasing use of man-made fibres, particularly of the polyester and polyacrylic varieties, partly solves the problem. Nevertheless, at present and for many years to come, the basic fibres for a large assortment of apparel goods in many countries will be cotton, wool and the rayons. With these fibres, the desired improvements of wearing properties can be achieved solely by chemical treatment with substances such as the precondensates of thermosetting resins. In the more developed countries, almost all rayon and cotton apparel fabrics are treated with resins to achieve crease-resistance and shrinkage-resistance. The range of resins employed for these purposes is quite wide, including urea-, melamine-, ethylene urea-formaldehyde methylolo derivatives, triazone compounds, acetals, epoxy compounds or vinyl sulphonium compounds. However, at this time the urea-formaldehyde and ethylene urea-formaldehyde compounds, known as reactants, maintain their place as the most important resins in commercial processes. This is true primarily because of their low cost and the relatively good results obtainable with them.

It is well known that the ideal crease-resistant finish (the so-called "easy-care"), is one which would produce a fabric capable of smoothing itself under all conditions of use, whether dry or wet. During the search for improved resins for this purpose, combined treatment with triazone resins, carbamates and sulphones was developed. Although crease-resistant finishes have been used for many years, some problems must still be solved; for example formaldehyde and amine odour, decrease in abrasion and tearing strengths and discolouration of fabrics when treated with certain resins.

Water-repellent finishes

Treating fabric to make it water-repellent is perhaps the oldest of the functional finishes. However, until the end of the Second World War, the water-repellent finish, mostly semi-permanent, was applied almost exclusively to fabrics intended to protect the human body or some objects against rainfall. At present, with the newly developed impregnation agents, water-repellent finishes are applied to suitings, dress goods, furnishing fabrics and the like, protecting them not only against staining with aqueous solutions, but also with greases and oils.

The water repellents presently in use may be classified into the following groups: zirconium-wax emulsions; fatty derivatives of quaternary pyridinium, such as Hydrofobol IW (Poland), Velan PF (United Kingdom) and Zelan (United States); fatty derivatives of melamine resins, such as Melafob S (Poland) and Phobotex FTC (Switzerland); chrome-fatty acid complexes, such as Hydrofob CR (Poland), Phobotex CR (Switzerland), Quaillon (United States) and Quintalan W (United Kingdom); silicones, such as ICI Silicones and Midland-Silicones (United Kingdom); and fluorocarbons, such as Scotchgard FC-205 and Zepel B (United States).

Zirconium-wax emulsions are cheap and easy to use as semi-permanent water repellents. They can be used on all fibres. If improved fastness to dry cleaning will be required, the wax repellents compete favourably with silicones. Ten or fifteen years ago, the pyridinium repellents were the most wash-fast repellents available, and they were used very widely for both military and civilian clothing. They are hardly used at all at present as straight repellent finishes but they are used in conjunction with fluorochemicals or as softeners, especially with resin finishes. A disadvantage of these compounds is that they have a very strong smell of pyridine and must be washed to remove this unpleasant odour. The handle obtained is rather soft, and this can be advantageous or disadvantageous, depending on the end-use of the fabric.

Water repellents based on melamine resins are used chiefly on cotton, cotton-blended fabrics and rayon fabrics. In some cases they are also applied to man-made fibres. An advantage of these compounds is that they do not require after-washing of fabrics treated with them.

The chrome-fatty acid complexes normally applied in finishing have fairly good durability. They are mainly used for wool, but they can also be used for cellulosic fibres without decreasing their tensile strength. Neither catalyst nor curing is needed. Because of their greenish colour, chrome complexes must not be used for treating of white fabrics or those dyed in pale shades.

Silicone repellents have good durability and are particularly fast to dry-cleaning. They are used generally for man-made fibres, but cotton and wool fabrics can be also treated with them. They are generally applied with a catalyst. The mechanical strength and sewability of fabrics treated with silicones are excellent

With both oil- and water-repellent treatments, it is generally best to use a finishing formula that includes fluorocarbon derivatives plus an extender or auxiliary-type water repellent. An example of this is the Quarpel finish (United States), which provides both oil and water repellency with excellent fastness to washing and dry-cleaning.

Modern water-repellent finishes are a vast improvement over those used even ten years ago, but they are by no means perfect. In practice, the actual performance of the durable water-repellent finish is often less good than was indicated by the testing data, since it is the practice of many cleaners to leave dry-cleaning detergents in the fabric, which effects water-repellency very adversely.

Flameproofing

At one time, only theatre curtains and special protective garments were flameproofed. Today, however, the range of flameproof fabrics used is best shown by the fact that, for example, all textile goods on board a ship, from carpets to bed and table linen must be flame resistant. In some countries (for example, in the United Kingdom), flameproofing of childrens' clothing is required by law.

Generally speaking, flameproofing techniques have been quite similar in all countries. The finishes are based on metallic oxides, chlorinated paraffin, Bancroft processing (United Kingdom), phosphonium derivatives (THPC), triallylphosphates (BAP) and the like and are applied to a very large assortment of textiles, from heavy-weight industrial fabrics to light apparel goods. A very recent trend is the production of flame-resistant fabrics made of fire-resistant fibres.

Mothproofing

Mothproofing of wool and other animal fibres is effectively achieved today by the impregnation of the fibres with chemicals that make them unusable as food by moth larvae. Chemicals such as silicon fluoride and chromium fluoride are used, but each of the various trademarked processes, such as Dilmoth (United States), Eulan (Federal Republic of Germany), Improwad AD (Poland) and Mitin (Switzerland), utilizes different compounds. The better processes are quite resistant to both laundering and dry-cleaning, are colourless, odourless, non-toxic and non-allergic, and do not change the handle of the cloth.

Anti-static finishes

One disadvantage of fabrics made from synthetic fibres is their tendency to accumulate charges of static electricity. At present, this phenomenon is considered not only from the aesthetic and comfort standpoints but also as a source of danger. In the last few years, static electricity has been recognized as a fire and explosion hazard in everyday life.

Hospital explosions traceable to the accumulation of static electricity on the non-conducting surfaces of sheeting, explosions during refuelling operations, and even the flammability of some sports clothing made from synthetic fibres have become increasingly conspicuous in recent years. It is thus evident that there is a real need for the inclusion of anti-static treatments in modern textile-finishing technology.

Recently, some fabrics have been impregnated with anti-static agents such as Arcostat (Federal Republic of Germany), Nonax 975 (United States) and Zerostat (Switzerland) to prevent the fibres from accumulating electrical charges during wear. Some disadvantage of these finishes as they now exist are low fastness to laundering and, in some cases, the yellowing of the fabric (Arcostat P).

Bacteriostatic or hygienic finishes

Sanitized and Arigal, which are Swiss-registered treatments, are good examples if finishes of this kind. The effect is obtained by subjecting the fabric to a treatment that involves the use of chemicals classified as hygienic additives, which inhibit the growth of bacteria in the cloth. They are also supposed to prevent odour, prolong the life of the fabrics and to combat mildew and mould. Such treatments have been applied to shoe linings, coat linings, lingerie and underwear fabrics, luggage, surgical supplies and upholstery materials.

Multifunctional finishes

The primary types of such finishes can be combined. Consequently, there is a trend in textile finishing toward the development of multifunctional finishes, for example, waterproof and antistatic finish, water-repellent and crease-resistant finish, simultaneous dyeing and resin finish, and so on.

A result of the progressive development of permanent finishes is the increasingly popular "permanent-press" finish. This process permits permanent creases and pleats to be formed during the making-up of garments such as trousers and skirts.

Wet-to-wet method

The cost factor is of great importance in textile finishing. For example, operations such as drying and curing are recognized to be both expensive and time consuming. However, in some cases, there is a possibility of impregnating the fabric by a wet-to-wet method, omitting interoperational drying after the scouring of the grey fabric.

This method is based on the impregnation of wet, scoured fabric with concentrated solutions or dispersions of finishing agents and drying them in modern frame-drying machines that have stabilizing fields, thus eliminating a separate curing operation. With these machines, fabrics impregnated with resin solutions or dispersions are dried in the drying field and then cured directly in the stabilizing fields for only 40 to 60 seconds at temperatures from 180° to 200°C instead of having to stay in a separate curing oven for 5 to 7 minutes at temperatures from 140° to 150°C.

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FINISHING KNITTED FABRICS

by

Z. Machnowska and H. Cichowski

The bleaching, dyeing and finishing processes for knitted fabrics are generally rather similar to those applied for woven fabrics and depend on the kinds of fibres used. However, because of the specific features of knitted fabrics, such as their tendency to deformation and difficulties in maintaining their aesthetic appearance and pleasant handle, progress in the finishing technology of knitted goods has developed rather differently from that of other branches of the textile industry.

The main emphasis is on machine construction that will assure the tensionless running of fabrics during the finishing operations, especially during wet treatments. Machines and equipment for knitted goods should also ensure mild processing conditions that will not affect the quality features of the processed fabrics adversely.

The development of knitted fabric finishing began with the introduction of the new synthetic fibres into the textile industry, which often required improved processing methods so as to give them certain positive features and wearing properties.

The general development trends for basic finishing operations, taking as reference level the previously existing technology, are discussed below.

Scouring and washing

For the scouring of knitted fabrics composed primarily of synthetic fibres, anionic detergents of the alkylsulphate type (Pretepon G or Sulfapol PW) or non-ionic detergents of the Alfenol 710 and Sulfapol E 20 type are used (all of those are Polish). Good results can be obtained, especially for synthetics, if trisodium phosphate is added to the scouring liquor, because of its swelling action and pilling-control properties. The use of this compound is particularly important for knitwears produced from textured yarns. When the fabrics are soiled with oils, it is advisable to add to the scouring bath a detergent such as Lavon (Poland) that contains organic solvents.

Fabrics can be scoured in open-width or in rope form, but rope scouring is the more conventional and most popular. Normally, scouring is carried out on the winch washing machine, but this method of scouring, especially when running the fabrics before pre-setting, entails a danger of forming undesirable permanent creases. Improvement in this wet processing equipment involves constructional changes; for example, the modern winch washers have a circular rotating roller, instead of an elliptical one, which is situated as closely as possible over the scouring bath surface. The steam heating pipes or other heating devices are mounted in the lower part of the winch washer and are separated from the working part by a perforated bottom. This arrangement ensures the uniform distribution of heat in the bath. It is a very importat advantage for the pre-shrinking and relaxation treatment of knitted fabrics that contain high-bulk fibres.

A better but still not enough used method is the scouring of knitted fabrics in open width. This method prevents forming of permanent creases. However, there are some constructional difficulties in the development of open-width scouring and washing. A good example of existing open-width washers is the Rotomat manufactured by Gerber (figure 1) or Norton and Peter washing machine adapted for knitted fabrics (figure 2).

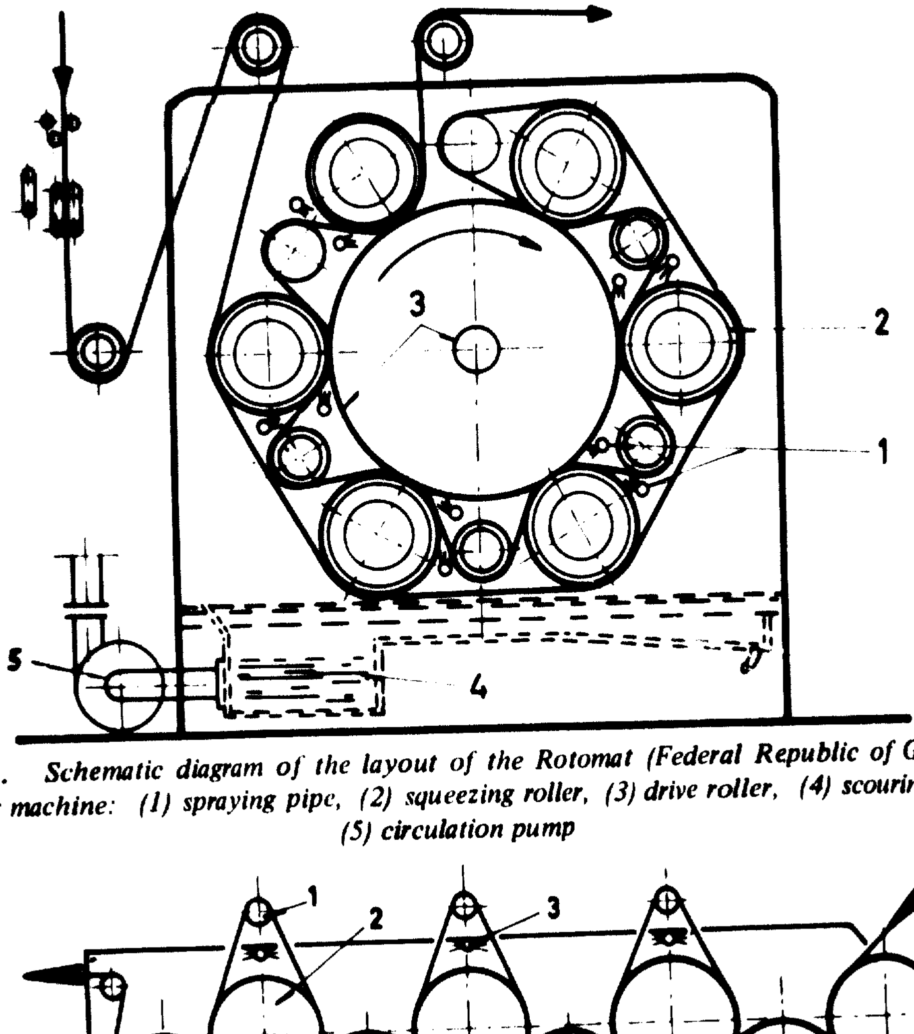

Figure 1. Schematic diagram of the layout of the Rotomat (Federal Republic of Germany) washing machine: (1) spraying pipe, (2) squeezing roller, (3) drive roller, (4) scouring liquor, (5) circulation pump

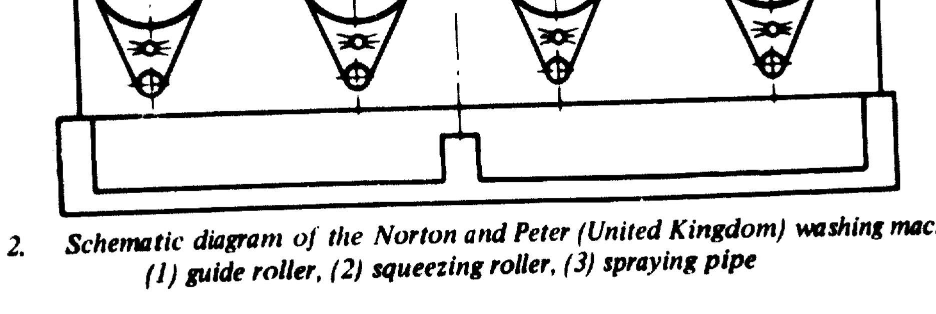

Figure 2. Schematic diagram of the Norton and Peter (United Kingdom) washing machine: (1) guide roller, (2) squeezing roller, (3) spraying pipe

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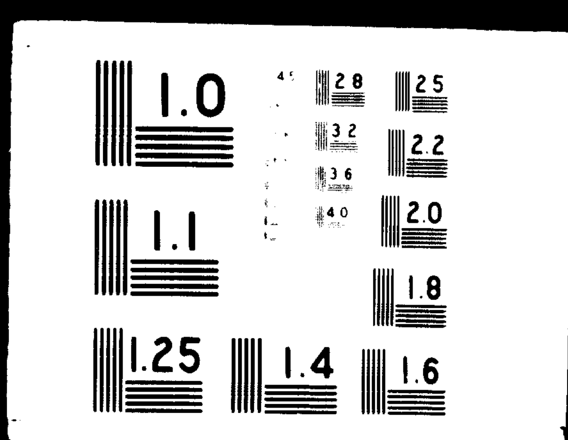

Bleaching

Bleaching methods for knitted fabrics are determined by the fibre used as raw material. However, for bleaching knitted goods made from cellulosic fibres, the commonly called "combination bleaching", that is, hypochlorite-peroxide bleaching, is widely used. Combination bleaching consists in running up on winch washers in baths that contain, successively, hypochlorite, hydrogen peroxide stabilized with sodium silicate, and an optical bleaching agent. An advantage of this method is that good whiteness is obtained without the previous kier boiling that is normal for woven fabrics but which is dangerous for knitted goods. During kier boiling, irreversible morphological changes of fibre structure occur that could impair the quality of knitted fabric seriously.

A recent trend in bleaching is the introduction of continuous treatment in open-width or rope form on specially aggregated machine sets. The continuous processes that have been in use for many years in the finishing of woven fabrics may perhaps be adapted for finishing knitted fabrics. This possibility is being investigated. However, the characteristics of knitted fabric finishes differ from those found in the other branches of the textile industry.

The short production runs and wide variety of products that characterize knitted fabrics do not favour the introduction of continuous processing methods. Nevertheless, in recent years some tendency toward the aggregation of finishing machinery has been observable in the knitting industry. Short machine aggregates that are accurately adapted to bulk production could be very economical, and in many cases the finishing effects might be much improved.

Of importance in the bleaching of knitted goods made from cotton and cotton-viscose blends is the continuous range in which such operations as wetting, chlorination, batching, bleaching and rinsing are all done on the machine set shown schematically in figure 3. The knitted fabric is wetted in the washer with a solution of wetting agent and soda ash, and is then chlorinated in another washing machine or padding bowl with a hypochlorite solution that contains 2 to 4 g/litre of active chlorine. After this step, the fabric is run through a J-box for 60 to 90 minutes at room temperature. After a short rinsing, the fabric is bleached in the washer or padder with hydrogen peroxide and run through a second J-box at a temperature of 100°C. The final operation is thorough rinsing in a washing machine. The results obtained by this method are considered as good. The cotton scales and waxes were removed, and an average whiteness of 80 to 82 per cent was achieved, and the rate of fibre degradation did not exceed the permissible level.

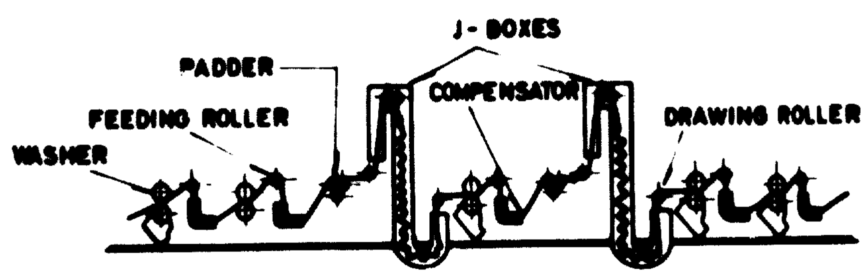

Figure 3. Schematic layout of a continuous bleaching range

All wool yarns and knitted fabrics are bleached by the oxidation-reduction method, using hydrogen peroxide and hydrosulphite or zinc formaldehyde sulfoxylate. For bleaching yarns and goods made from wool-viscose rayon blends, the peroxide method is applied. If increased whiteness is required, the knitted fabrics or yarns are treated after chemical bleaching with an appropriate fluorescent optical bleaching agent.

The chlorite bleaching process is applied for bleaching the polyacrylic yarns so widely used in the knitting industry. A difficulty with this modern method, which gives good whiteness, is that very toxic and corrosive gaseous chlorine dioxide is evolved. (Chlorine dioxide also attacks some stainless steels.) Because polyacrylic fibres are generally bleached in bulk, it is necessary to correct only the whiteness, using a suitable optical bleaching agent, such as Blancophor (Federal Republic of Germany) or Leucophor (Switzerland) instead of the difficult chlorite process.

A similar optical bleaching system is applied for polyamide knitted fabrics. The most popular of these are those of the milanese type, knitted on flat warp-knitting machines. Modernization of bleaching methods for knittings of this type is based on introducing high-pressure autoclaves into the process. These devices represent a considerable advance in finishing processing. They are used primarily for dyeing. (Optical bleaching may be considered as a specific kind of dyeing.) Knitted fabrics are wound on the perforated beam, brought into the autoclave chamber, and the autoclave is closed by means of a quick-acting locking device. Throughout this treatment, the corresponding bath is circulated in such a way that it is pumped from the filled autoclave and forced through the beam with the wound goods back into the autoclave. The principal difficulty with this method is the proper winding of the goods on the beam. Knitted fabrics must be very carefully and uniformly wound, with constant tension and without creases and folds that may be set during the process.

Dyeing

High-pressure autoclaves for dyeing have been used for only a few years in the knitting industry and have reached their present level of development only recently. However, it is expected that, in the very near future, they may give way, partly, to continuous dyeing methods.

In continuous dyeing, the knitted fabric is padded with a solution containing dye and thickener. The fabric then passes through the reacting chamber, where fixation of the dye takes place. In the American Thermosol method, fixation is carried out in the heating fields of a setting machine, simultaneously with the setting. An advantage of this dyeing method, as compared with non-continuous dyeing, is its economy. The rate of productivity is increased and dyeing quality is improved, especially as regards the "stripy" effect. It has been observed that, with polyamide knitted fabrics, stripiness almost disappeared after Thermosol dyeing. The results are superior to those obtained with any other dyeing methods, including modern high-pressure beam dyeing.

The obstacles met in the application of the continuous dyeing method mainly concern the means for guiding the edges, which show a tendency towards curling. According to recent information, the leading manufacturers of textile machinery are actively interested in this problem and will probably solve it very soon.

Chemical finishing

Strictly speaking, the finishing processes for knitted fabrics can be divided into two parts: chemical and mechanical finishing. However, mechanical finishing is more developed than chemical finishing.

As regards the chemical finishing of knitted fabrics, in addition to scouring, bleaching and dyeing, almost entirely chemical treatments are applied for improving the handle of goods by the introduction of softeners or filling agents. To a minimum extent, shrinkproofing treatments are applied to cellulosic knitted goods. For this purpose, thermosetting resin precondensates are used as cross-linking agents. Although this process has been widely used for woven fabrics for many years, it is not popular for knitted ones, primarily because there is a lack of suitable machinery and equipment.

Other chemical finishes that are objects of current research works and industrial trials include anti-pilling, anti-static, hygienic and hydrophilic finishes.

Pilling occurs on knitted fabrics that contain staple synthetic fibres. On surfaces of these goods, the free fibre-ends form pills during wear. This phenomenon may be eliminated by the introduction of chemical agents that decrease the coefficient of friction between individual fibres. For this purpose, thermoplastic resins (mostly polyacrylic) or other chemical compounds such as zinc chloride are used.

The hydrophobic nature of synthetic fibres constitutes a considerable disadvantage, especially for use in underwear fabrics. This negative feature may be eliminated by introducing into the fibres some hygroscopic and humidity-retentive compounds. For this purpose, auxiliary agents based on hydroxypolyamide such as Lurotex A 25 are used. Finishes of this kind are effective, although their launderability is rather poor.

Another disadvantage of knitted fabrics made from synthetic fibres is their tendency to accumulate charges of static electricity. The impregnation of the fabric with such anti-static agents as Arcostat (Federal Republic of Germany), Nonax 975 (United States) or Zerostat (Switzerland) prevent the fibres from accumulating static electricity during wear. A disadvantage of this finish is a low launderability and, in some cases, the yellowing of the goods (Arcostat P).

Mechanical finishing

The physical and mechanical operations performed on them exert decisive influence on the quality and aesthetic appearance of knitted fabrics. One of the basic operations of this type of treatment is steaming, which is recommended for knitted goods made from all kinds of fibres, both natural and synthetic. During tensionless steaming, all stresses introduced during the knitting process are removed from the fabrics. As a result of steam treatment, the goods gain a very soft and pleasant handle.

When thermal setting treatments of synthetic fabrics are considered, steam setting is usually reported to be excellent. Unlike setting by hot air or hot water, steam setting does not affect the handle of fabrics adversely but rather improves it. Steam setting is especially important in fabrics knitted from textured yarns.

There are several different devices for the steam processing of knitted goods. They vary according to the required conditions of the process and to the form of treated fabric. For piece steaming of tubular and flat knittings, Héliot's decating calender (France) may be used. The cardinal advantage of this machine is the possibility it offers of steaming the goods under minimum tension when roller pressure is completely eliminated. For full-fashioned goods, steaming plates are used. These very simple devices give good results, especially for polyacrylic knitted fabrics.

In the case of steam setting, in which the conditions are more severe than those found with hot-water setting, modern fully automated vacuum-pressure autoclaves are used. These machines are adapted for piece knitwear, which are wound on perforated beams, or for full-fashioned goods boarded on metal forms.

As regards purely mechanical processing, compressive or relaxation shrinking should be mentioned. The primary role of this operation is to eliminate all tensions formed in the fibres during spinning, winding, knitting and finishing. Knitted fabrics finished in this way are characterized by good dimensional stability, levelling of stitches and very soft handle. These features improve the aesthetic and wearing value of the goods considerably. Some special machines have been developed for such processing. An example is the Bestan machine manufactured by Hunt and Moscrop Ltd. (United Kingdom). The operating principle of this machine is based on the differential speed and the differential coefficient of friction of a pressure feed roller and a retarding roller, independently controlled, which operate in conjunction with a heated bedplate. A simplified schematic diagram of this system is presented in figure 4.

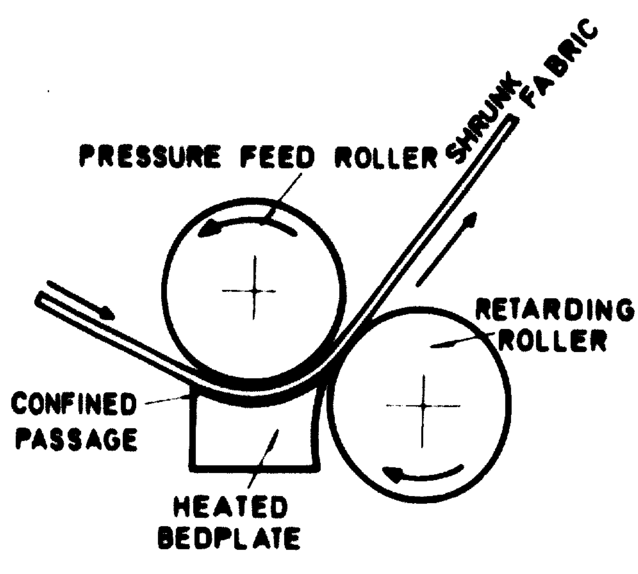

Figure 4. Diagram of the principal components of the Bestan mechanical finishing machine, showing the movement of the material through a confined passage

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INSTRUMENTAL COLOUR MATCHING AND TRENDS OF ITS APPLICATION

by

H. Cichowski

The formulation and control of colour in manufacturing processes has gained increasing importance everywhere. Visual judgement has served well in the past, but with the demands for higher standards of quality as well as productivity, traditional methods of colour-matching require increased precision and objectivity. The traditional method of assessment, carried out by the unaided eye, is prone to wide errors and is dependent on the experience of the inspector, the colour composition of the sample, lighting conditions and the effect of subjective factors such as health.

At this time, when increasing development of colour-measuring instruments and of various analogue and digital computers permits the resolution of practically all kinds of differential equations, and when the standardized colour system introduced in 1931 by the International Commission on Illumination (Commission Internationale de l'Eclairage CIE) has been accepted all over the world, real opportunities for practical application of colour measurements in various branches of textile industry will exist.

Before discussing the practical application of colour measurement in the textile industry, a brief account of the CIE system should be given. This colour system provides a basis for the conversion of spectrophotometric measurements into colour specifications. It is based on the principles of additive colour mixing. Most surface colours can be matched visually with an additive mixture of red, green and blue light. In the CIE or XYZ system of colour specification, the chromaticity co-ordinates are defined in term of the units or tristimulus values X, Y, and Z, so that

$$q\,(C) \equiv X\,(X) + Y\,(Y) + Z\,(Z) \qquad (1)$$

the required chromaticity co-ordinates of (C) are given by:

$$x = \frac{X}{X+Y+Z}\,;\quad y = \frac{Y}{X+Y+Z}\,;\quad z = \frac{Z}{X+Y+Z}$$

The CIE chromaticity diagram in figure 1 shows the spectrum locus and approximate hue areas. One important feature of this system is that the Y values are identical with the illumination factor, which is the third factor needed for complete characterization of every coloured surface; namely, hue, saturation and lightness.

So, according to the CIE system, every colour may be specified objectively by the three dimensions x, y and Y.

In order to convert a spectrophotometric measurement into a CIE specification it is necessary to know the effect on the eye of different wavelengths throughout the visible spectrum. This effect varies with the observer, so that the CIE system defines

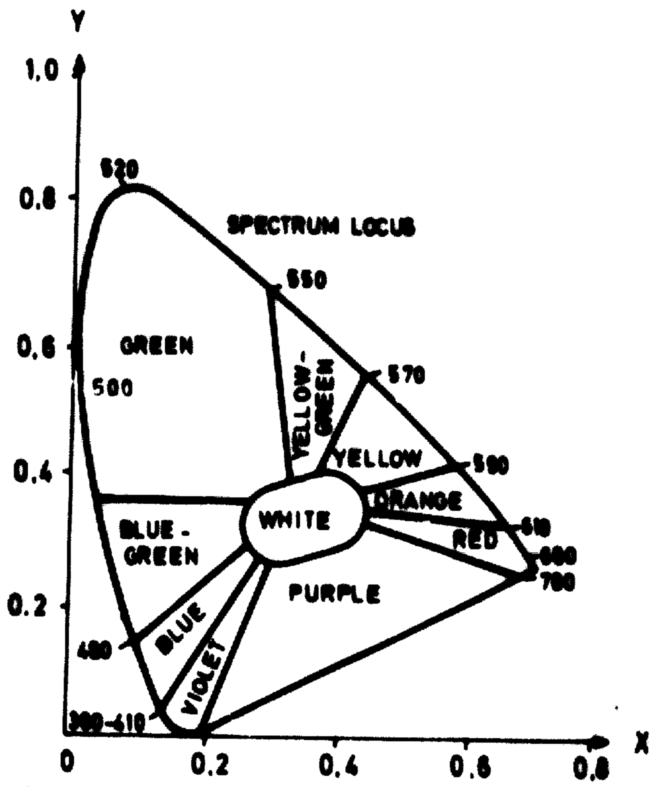

Figure 1. CIE chromaticity diagram (the numbers on the spectrum loci are wavelengths in nanometres)

an average effect in the form of the colour-matching functions of the so-called standard observer. These functions are obtained by measuring the amounts of the standard red, green and blue stimuli required to match spectral lights at 5 nm intervals throughout the visible spectrum from 380 to 780 nm. The tristimulus values

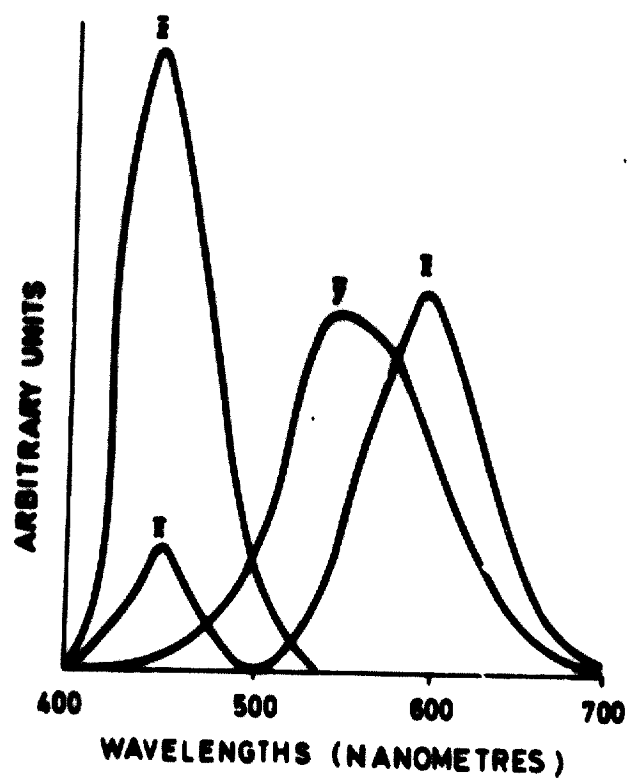

Figure 2. CIE distribution coefficients

for the equal-energy spectrum, shown in figure 2, are sometimes known as distribution coefficients or colour-matching functions and are denoted by $\bar{x}$, $\bar{y}$, and $\bar{z}$. It is very convenient to regard these curves as representing the sensitivity of response of the eye.

If the values of $\bar{x}$, $\bar{y}$ and $\bar{z}$, the values of relative distribution of energy in the light source E under which the coloured surface is seen and the value of reflectance R as a function of wavelength are known, it is possible to describe the sample in terms of its tristimulus values X, Y, Z which can be computed from equation (2):

$$X = \int_{780}^{380} E \bar{x} R d_{\lambda}$$

$$Y = \int_{780}^{380} E \bar{y} R d_{\lambda} \qquad (2)$$

$$Z = \int_{780}^{380} E \bar{z} R d_{\lambda}$$

The value of $\bar{x}$, $\bar{y}$, $\bar{z}$ and E, which are different for each wavelength, have been standardized by the CIE and are taken from their data tables. The reflectance R is measured on spectrophotometer. Another but less accurate way of describing a colour in terms of its tristimulus values X, Y and Z is by measurement of the sample on the tristimulus photocolorimeter.

From the point of view of the textile dyer and finisher, the great importance of the standardized CIE system depends on the fact that trichromatic characterizations of a given colour tend to be more specific than such terms as, say, tender pink, fresh green, snappy red or sexy purple.

Recent trends in the application of colour measurement in textile finishing

The present state of the art of colour measurement permits its use in the everyday practice of textile finishers and dyers. Among the many practical applications, the following three trends seem to be the most important:

(a) Determination of colour differences between dyed fabric and a standard sample;

(b) Instrumental colour-match prediction;

(c) Colour control in continuous dyeing processes and colour sorting.

Determination of colour differences between dyed fabrics and a standard sample

Over the past few years many textile producers have come to realize that greater control of colour is absolutely necessary. Today, much time and money are lost simply because colour examiners cannot agree. If such phenomena as metamerism, dichroism and eye fatigue are considered, it is easy to understand the reasons for such disagreements. However, it is possible to eliminate the subjective elements from colour-matching and to compute the quantitive colour differences by incorporating the photocolorimetric instruments into the dyeing process.

Important colour-difference equations have been summarized by Warburton (1963), and the subject is treated in detail by Judd and Wyszecki (1964). A good example of simple, rapid, graphic computation of small colour differences is the Simon and Goodwin method based on discrimination ellipses, such as those of MacAdams (1958). The data of MacAdams are published in the form of a number of charts by the Union Carbide Plastic Corp. (United States). Chromaticity data from the control pattern may be plotted on these charts, and the colour difference read off directly in American National Bureau of Standards (NBS) units.

From the point of view of producers and customers, the objective colour-difference measurement should be treated as a step toward colour tolerance. However, tolerance from standard is an absolute necessity in textile dyeing and finishing, just as it is at this time in the steel, machinery and other industries.

Instrumental colour-match prediction

Shade matching and recipe formulation are probably the most difficult and time-consuming features of the dyers' work and cause considerable delays in completing orders. The problem is intensified with the introduction of new ranges of dyes or when the need for particular colour fastness or cost requirements are concerned.

In recent years several different systems of instrumental recipe formulation based on the use of analogue or digital computers have been developed. One of the most important advantages of these systems is that the smallest number of suitable dyestuffs can be used to match the widest possible range of shades. Because of the increasing popularity of instrumental colour-match prediction systems, some theoretical information and brief descriptions of existing systems are given below.

Colour control in continuous dyeing processes and colour sorting

Colour control of new recipes in continuous dyeing is now feasible with the aid of continuous colour measurement of the dyed fabric with a photocolorimeter or spectrophotometer. The composition of the dye-bath may be set initially according to a computer prediction, and the run commenced. Colour measurement of the dyed material and standard sample are compared continuously, and the necessary adjustments of the dye concentration are calculated automatically by a computer supplied with the shading factors obtained initially with the dye prediction. Successful operation of such a technique depends, of course, on the rigid control of the dyeing conditions and the solution of many practical problems.

Instrumental colour-match prediction as a tool for the colourist

Two colours may be said to match if their tristimulus values X, Y and Z are the same. On the other hand, two colours are the same if their reflectance curves are identical for a given source of light.

According to Fink-Jensen (Alderson, Atherton and Derbyshire, 1961), the relation between reflectance of the dyed fabric as a function of wavelength and concentration (that is, the mixture of three dyestuffs) may be illustrated by the equation:

$$\frac{1}{R_\lambda} = \left(\frac{1}{R_\lambda}\right)_s + \delta_{\lambda_1} c_1 + \delta_{\lambda_2} c_2 + \delta_{\lambda_3} c_3 \tag{3}$$

where:

R_λ = reflectance coefficient of dyed fabric for given wavelength,

$(R_\lambda)_s$ = reflectance coefficient of undyed substrate,

c = dyestuff concentration,

δ_λ = coefficient of absorption for given dyestuff.

After mathematical modification of equation (3) to the form:

$$R_\lambda = \frac{1}{\left(\frac{1}{R_\lambda}\right)_s + \delta_{\lambda_1} c_1 + \delta_{\lambda_2} c_2 + \delta_{\lambda_3} c_3} \tag{4}$$

three differential equations for calculation X, Y, Z may be formulated:

$$X = \int_{400}^{700} \frac{E_\lambda \bar{x}_\lambda \, d\lambda}{\left(\frac{1}{R_\lambda}\right)_s + \delta_{\lambda_1} c_1 + \delta_{\lambda_2} c_2 + \delta_{\lambda_3} c_3}$$

$$Y = \int_{400}^{700} \frac{E_\lambda \bar{y}_\lambda \, d\lambda}{\left(\frac{1}{R_\lambda}\right)_s + \delta_{\lambda_1} c_1 + \delta_{\lambda_2} c_2 + \delta_{\lambda_3} c_3} \tag{5}$$

$$Z = \int_{400}^{700} \frac{E_\lambda \bar{z}_\lambda \, d\lambda}{\left(\frac{1}{R_\lambda}\right)_s + \delta_{\lambda_1} c_1 + \delta_{\lambda_2} c_2 + \delta_{\lambda_3} c_3}$$

All of the data from these equations are known except the concentrations c_1, c_2 and c_3. Solution of these differential equations in the usual way is a rather difficult and time-consuming task. However, if an analogue or digital computer is used, the required dyestuffs concentrations, together with shading factors, may be calculated in a very short time – from a few seconds to several minutes.

Instrumental colour-matching systems

It is interesting to note how similar the procedure followed by the computer is to that of the human colourist. Both assess the pattern to be matched by observing the light reflected from its surface; both call upon memory and acquired experience to inform them of the optical properties and dyeing behaviour of the individual dyes to be used, and both perform the calculations or exercise judgements to arrive at a trial recipe. At this point the colourist normally makes trial dyeings, using recipes showing slight variations, until he finally achieves a dyeing identical with the sample to be matched. Even with a skilled and experienced colourist, all this may take several hours, but the digital computer does it in less than a minute. The principles of instrumental colour matching are diagrammed in figure 3.

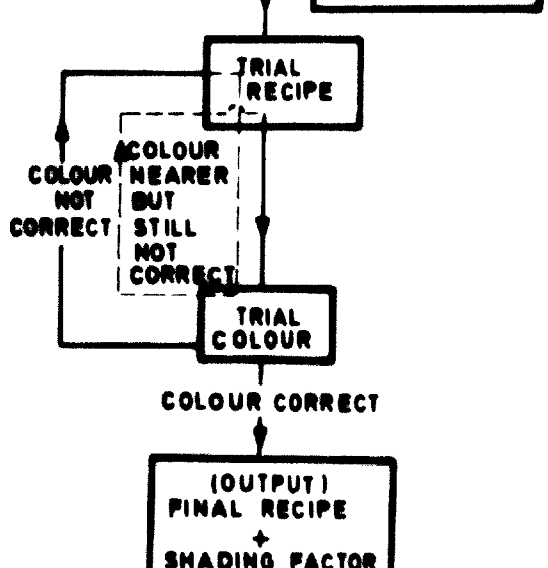

Figure 3. Principles of instrumental colour matching

Several approaches have been made toward the achievement of accurate colour-match prediction. Both digital and analogue computers have been used for this purpose, the following techniques being among the most important.

The Colourant Mixture Computer (COMIC) is an analogue computer made by Davidson and Hemmendinger in the United States. It uses the Kubelka-Munk relation to determine the concentrations of dyes required to give a dyeing, the spectral reflectance of which equals that of the sample to be matched (Davidson, Hemmendinger and Landry, 1963). In the last few years, similar instruments have been developed in Switzerland and the United Kingdom. These are respectively, the Pretema Colour Computer (Rohner, 1966) and the Redicolor (Drewe, 1968).

The Instrumental Match Prediction (IMP) system was developed in the United Kingdom by Imperial Chemical Industries, Dyestuff Division (Alderson *et al.*, 1963). It employs a digital computer to solve an equation suggested by Fink Jensen (Alderson, Atherton and Derbyshire, 1961), which is similar to the Kubelka-Munk relation. Values of the required dye concentrations are calculated by the computer in such a way that the spectral reflectance of the predicted dyeing yield the X, Y and Z values of the sample to be matched. A correction matrix is also produced to enable the dye recipe to be adjusted, if necessary.

The American Cynamid Company (United States) is operating a system of instrumental match prediction by digital computer called Computer Colour Matching (CCM). It is similar to the IMP system and is now sufficiently developed for wide application (Allen, 1965; Wright, 1964).

A very precise system of instrumental colour-match prediction has been developed in Switzerland by Sandoz (Gugerli, 1966). This system, called SARFO, employs a digital computer. In addition to the colour recipe, the calculations yield the spectral reflectance curve of the calculated match, and detailed colorimetric data on the metamerism to be expected and the probable hue stability of the match in different light sources, as well as other information. In addition, two different correction matrices are calculated for each recipe.

It should be noted that only two of these systems, COMIC and IMP, are in everyday use at this time. In 1965, the COMIC computer was used in about 125 dyeing-department laboratories all over the world. The IMP service was introduced by the ICI Dyestuff Division in 1963.

In discussing these systems, it would not be correct to assume that instrumental colour matching deprives the dyer of any of his basic skills. It is an added tool that enables him to perform his function more rapidly and economically. However, in order to make the fullest use of this new and expensive tool, the dyer must add some knowledge of colour physics, mathematics and even of electronics to his already wide range of information.

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