New developments in dyeing process control

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Present textile market is buyers' market. The consumer dictates the terms as far as the quality, quantity and delivery schedule are concerned. To withstand such competition, the manufacturers/processors have to adopt total quality management approach so that not only they get the goods processed right at the first time, but quality is ensured. Increasing environmental pollution awareness has thrown new challenges before the textile technocrats. The present paper reviews the new developments in the field of dyes manufactured, methods of application and machinery used. It also takes into account the impact of advent of micro fibres and specific developments in processing of terry-towels, garments, etc. The future trend is also predicted based on all the above factors.

Keywords: Dyeing, Disperse dyes, Reactive dyes, Polyester fibre, Cellulosic fibre, Wool fibre, Silk fibre, Dyeing machinery

1 Introduction
The globalization has widened the scope of the textile business with the inevitable entry of international competition. The challenges and opportunities are increasing and the appropriate response has to be evoked in terms of technological advancement and on-time delivery. Such "quality and quantity" supply has to be done on the basis of right-first-time, right-every-time, quick response approach. While this is being attempted, it is also incumbent to consider reduction in energy and production cost. The challenges posed by this decade revolve around the conservation of environment, an issue which has aroused the attention at global level and will direct the future chemical technological advancements predominantly.

The emergence of new materials such as polyester microfibres, increasing applications of computer technology for recipe prediction as well as for expert systems of dyeing and finishing, and the increasing use of microprocessor-based process monitoring and control equipment will stimulate the fine tuning of our production efficiency and effectiveness as well as economy. The opportunities placed before us, of course with a package of challenges, in post-GATT period need to be exploited and it is the technological advances which will be playing major role in shaping the destiny of this industry.

When one talks about technological advancements in dyeing process control it is natural that the majority of these advances are concentrated on dyeing of woven fabric. However, dyeing of garment, terry-towel, microfibre and hosiery or knit goods also account for a sizable production and some developments in this respect need to be also summarized. The advancements in dyeing processes have bearing on the developments in dyes and newer applications.

The colouration and finishing are the key stages in imparting fashion appeal to the textile apparels. The timing and positioning of colouration in the handling of textiles are essential factors in ensuring that a chosen market is supplied with the right product at the right time and in right quantities as well as at the right price.

The first aspect of Quick Response (QR) to consider is the shortening of the traditional pipeline by eliminating unnecessary inventories and optimization of process times. Learning to operate with significantly lower stocks of raw materials and finished goods is no simple matter because so many new disciplines must permeate the organization. One such new discipline is the Right-First-Time concept in wet processing. The objective is to avoid unnecessary activity and complexity—wasted time, wasted energy, wasted material and correction of errors. This in positive terms means quality management (QM).

As far as the recent trends in dyeing process controls are concerned, they are the result of developments in dyes, fibres, application conditions and machinery.

2 Developments in Dyes
The technological developments in the dyestuff industry are taking place from the point of view of:
(i) High-performance products
Concentrated brands: To minimize neutral cutting agents and to incorporate useful additives.
Non-dusting brands: Granulated and liquid brands.
The use of non-dusting grains or powders and liquid brands of dyes help in minimizing air/water pollution and in application of automated dye dispensing systems.

(ii) Cost effectiveness
Increased automation, advanced instrumentation and controls, and computerization for the manufacturing operations with the objectives of high quality standards help in cost reduction and increasing profitability with quality production.

(iii) Health, safety and ecology
Selection of dyes is necessary from the points of view of:
- Avoiding the use of dyes which can form on reduction carcinogenic amines, and
- Selection of high exhaustion/fixation dyes, particularly among reactives.
Most of the product development has been concentrated in the field of disperse and reactive dyes. Some of the new dyes of these classes introduced in the market in recent years are briefly reviewed here.

2.1 Disperse Dyes
Disperse dyes are used to colour polyester. Anthraquinone dyes have much lower colour values and are more expensive although they give valuable bright red, blue and turquoise shades whereas azo dyes offer a full shade range and high colour values. With the advent of jet dyeing and thermosol application, the search for new chromophores has led to the development of benzodifuranone dyes of high colour value, brightness of shade, good substantivity and low thermomigration. Some of the new disperse dyes available are:
- Resoline Brilliant Red F 3GS (Bayer) has good fastness to dry heat fixation and high brilliance which is required for fashion polyester and polyester/cotton sports and leisure wear.
- BASF has introduced a new series of Palanil dyes in its Palanil disperse range – Palanil Black G, Red FFB, Navy Blue GN, Navy Blue-CF, Brilliant Blue BGFN and Brilliant Blue BGM-CF. These dyes are available as low-dusting powders/liquids.
Palanil Blue BGFN: Suitable for polyester blend dyeing, it is insensitive to dyebath pH and reduction. It has good fastness to heat-setting/wet treatments too.
- Navy Blue-CF: It is an extension to the Palanil CF (Controlled Fastness) series and is suitable for all dyeing processes.
- Brilliant Blue BGM-CF: It can be readily thermofixed and has good light fastness even at high temperature. It is particularly suitable for automotive textiles.
- Dispersol SF (Super Fast), a new range from ICI which includes black, navy, rubyine, yellow, blue and brown dyes specifically targeted for dull tertiary shades, a very difficult area for most dyers. They are alkali clearable dyes and exhibit extremely low cross-staining.
- The Dispersol XF range complements the ICI Dispersol SF (Super Fast) dyes which are benzodifuranone based.
- A fascinating area of disperse dye chemistry has been the development of high-value speciality colours giving brilliant fluorescent dyes. These are complicated, expensive structures involving sophisticated organic chemistry yielding brilliant shades with acceptable fastness properties.
- Zeneca (previously ICI) has introduced diester, thiophene and benzodifuranone based high fastness Dispersol dyes. They obviate the need for reduction clearing and are used in both exhaust and continuous dyeing.
- Murlow-Van Loan Corp. offers a new disperse black which claims excellent colour yield and exhaustion properties in dyeing of polyester.
- Black ASB Extra exhibits superior sublimation, light, wash and perspiration fastness properties and high alkaline stability, thus enabling to accomplish single bath dyeing of polyester/cellulosics with minimum staining.

2.2 Reactive Dyes
Of all the classes of dyes used for cellulose, reactive dyes account for 21% of total consumption of dyes in the world and show upward trend in their application for obvious reasons.
Recently, a new generation of bi- and polyfunctional dyes have been introduced which consist of homo or hetero reactive systems. As a result, exhaustion, fixation and migration can be controlled, leading to much improved dye fixation and better reproducibility. Some of the recent additions are reviewed here.
- Sumifix Supra range (bifunctional) has a high degree of exhaustion and fixation, resulting in less washing-off (hence less dye in the effluent), high
fastness to light, perspiration, peroxide washing and chlorinated water, and high stability to acid hydrolysis.

- Kayacelon reactive dyes are high-temperature neutral-dyeing dyes which are especially suitable for fast processing of cotton and one-bath dyeing of cotton, nylon, cotton/acyllic and cotton/polyester blends.

- Cibacron C range dyes (Ciba-Geigy) are bifunctional reactive dyes which have an aliphatic vinyl sulphonate group combined with either a monofunctional group with following features:
  - Suitable for pad application and exhaust dyeing at low liquor ratios.
  - Very good solubility and high to very high degrees of fixation.
  - Excellent wash-off, and
  - High fastness levels.

The environmental benefits include:
- No urea needed for dissolving the dye.
- Less dye in effluent due to high fixation, and
- Water and energy savings due to easy wash-off.

- Zeneca's Procion H-EXL exhaust dyes (bifunctional) have been engineered to produce high performance level dyeing, migration, diffusion and exceptional build-up properties.

Of the reactive dyes available today, new Remazol EF dyes significantly reduce waste in effluent, claims Hoechst. These dyes require 33-70% less salt than conventional reactive dyes.

- Provide higher fixation under low salt conditions as compared to conventional reactive dyes, and
- Are available in environmental safe packaging (low-dust powders or liquids).

- Rite Industries Inc. has launched the Rite Reactive B series of dyes which allow to reduce the amount of salt to be used in the dyeing with similar advantages.

- BASF has introduced five new reactive dyes into the Basilen range. These are Basilen Blue E-FRN, Blue E-BGF, Red F-RM, Red F-3BM and Yellow F-3RM. Basilen Blue E-FRN is a double anchor type monochorotriazine dye free of heavy metal which produces a unique royal blue shade and can be used on polyester/cellulosic blends by the BASF recommended process. Basilen Blue E-BGF is a brilliant blue dye free of heavy metals and stable under high-temperature dyeing conditions (e.g. polyester/cellulosic blend dyeing). The other three Basilen FM dyes have high exhaustion and easy wash out properties to decrease water usage and water contamination.

In Indian market too, a number of companies have come out with high-exhaustion and medium-exhaustion bireactive dyes which are finding increasing applications.

3 Developments in Application Methods

3.1 Polyester Fibres

During the dyeing of polyester fibres, the conventional dyeing liquor contains large amounts of dispersing agents and surfactants which are used to get reasonable rates of dyeing, ensuring levelness. This leads to an effluent loaded with dye and dispersing agents which is to be treated with an ever increasing cost. One radically new approach is to use supercritical CO2 medium for dyeing PET with dispersing dyes. After the dyeing operation is complete, dry dye powder, which has not been used up, deposits at the bottom. There is no necessity of dispersing agent or carrier. However, this dyeing requires dispersing dyes of special structural features, free from dispersing agents. Also, the cost of equipment and pipings is high. While the operational costs are very low as compared to that in conventional dyeing method (requires only 1/5th of the energy). There is also no requirement for reduction clearing treatments, washings, dryings, etc., thereby saving time and energy and providing protection to environment. This method looks to set further the cause of QR and hence QM.

Recently, Hoechst Mitsubishi Kasei (HMK) has made possible the dyeing of polyester in an alkaline medium, thereby making the entire wet processing simple and reproducible. The quality of dyed materials is also improved. In addition, the problems due to the presence of polyester oligomers in acidic dyeing conditions are also minimized.

The HMK system involves both alkaline-resistant dyes and a newly developed stabilizer PH95 for dyes for alkaline conditions. The stabilizer has many functions such as buffering the dyebath pH to around 9.0-9.5 during dyeing, stabilizing dyes, chelating metals and dissolving oligomers. The small variation in pH during the dyeing cycle promotes excellent reproducibility.

3.2 Cellulosic Fibres

Many ideas surround the concept of blind coloration, ranging from a simple no addition dyeing to the management of all those factors that affect the coloration of a textile, resulting in a right-first-time dyeing. The latter definition implies the total control of all factors (including the human ones) that can influence coloration and cause a shade to deviate from the standard.
The benefits of blind dyeing can be summarized as follows: cost saving, improved planning, better quality, increased productivity, customer satisfaction, etc.11

Dyeing with mono-functional reactive dyes is known to be rather sensitive to changes in dyeing conditions such as temperature, liquor ratio, addition of salt and alkali. A low sensitivity to dyeing parameters using dyes with two different reactive groups is particularly advantageous in continuous dyeing operations as it helps to achieve reproducibility of shades, i.e., right-first-time and every time.

The key factors influencing the rates of right-first-time production are dye selection, control of raw materials and on-line process control. In itself, improving the rate of right-first-time production can improve productivity by 20% and the return on sales to around 13% (ref. 12).

Right-first-time production will be maximized if these fundamental measures of performance within the reactive dye compatibility matrix RCM are set at:

- Substantivity: 70-80%
- Migration Index: > 90%
- LDF: > 70%
- T90, a minimum of 10 min

A comparison of RCM of individual dyes will provide a measure of the compatibility of dyes when they are used in combination. Dyes with similar performance and with substantivity, migration index, LDF, and T90 values within the target specification will offer robustness to small variations in processing conditions, shade reproducibility and level dyeing performance12.

Newer developments controlling additional parameters relating to the physical characteristics of the substrate take into account the influence of mechanical and hydraulic forces exercised by the machine during the process13. The control equipment allow the hydraulic and mechanical action of the dyeing machine to be adjusted, not only for the entire process but also for each period in the dyeing process. This principle is utilized in the synchron dyeing control system, which synchronizes liquor circulation, fabric speed and process cycle14.

The alkali dosing process is becoming popular as a rationalized dyeing method for reactive dyes15-8. Many types of reactive dye can be used, but the optimum pH range will depend on the nature of the dye employed. To control the rate of exhaustion, it is desirable to use a dye that reacts over a wide pH range so that the conditions can easily be controlled during dyeing. The Sumifix Supra range of dyes contain both a vinyl sulphone group and a monochlorotriazine reactive group. They react with cellulose over a wide pH range and are, therefore, suitable for use in such optimized dyeing processes15.

These dyes have been adapted both for exhaust dyeing and semi-continuous operations. High fixation, low substantivity and good diffusion, effecting rapid and efficient removal of small amounts of unfixèd dye, are the salient features of these dyes. To increase the fixation of dye, the one of the most popular alternative energy sources which could be used is radio-frequency (RF) energy.

Heating of the batch with radio-frequency energy during the batching stage greatly accelerated the rate of fixation. Fixation levels achieved using optimized RF-assisted methods were approximately equivalent to those achieved in conventional pad-batch dyeing16.

Dawson International, in 1978, patented a process and the equipment design used for fixing dyes or chemicals with RF energy16. The process involved continuous conveying of treated fibres through closely confined tube located between flat parallel electrodes. By generating RF energy field within the tube, a self-sealing pressure chamber was created by the formation of steam from the wetted fibres. The advantage claimed was an increase in the reaction rate of the dye on the fibre.

The semi-continuous pad-batch process using RF energy has also been recognized as one of the most efficient methods of applying reactive dyes to cellulosics with excellent reproducibility, leading to right-first-time every time concept.

Laser fixation is a feasible low-heat treatment method for line-line dye fixation. A comparison of wash fastness of hand-ironed and laser-treated specimens showed that the specimens treated with an argon-ion laser at 129°C and 235°C maintained color significantly better than the specimens treated with a lower laser heat (94°C) and hand iron (190°C). This was true for 10, 20 and 30 washes. A laser temperature of 129°C was as effective in setting fibre reactive dye in cotton as was a laser temperature of 235°C, indicating that a lower energy laser would be as useful in setting dyes as higher power models17.

Electromagnetic heating produces dyeings of similar shades to those obtained by conventional heating when pressure and temperature conditions are kept the same for both treatments. However, electromagnetic heating allows smoother and more homogeneous boiling than does conventional heating and can be useful industrially18.

Lewis and coworkers19 carried out fibre pretreatments aimed at dyeing with reactive dyes under neutral conditions.
ral to slightly acidic conditions in the absence of electrolytes. All of these treatments introduce cationic (basic) residues in the form of quaternary, tertiary and secondary amines.

One of the most convenient pretreatments was to apply polyamide epichlorhydrin resin to the cellulose fabric using pad-dry system. Selection of highly reactive dyes gave good colour yield on this type of fabric and the fixation of dyes proceeded simply by applying them from a dyebath set at pH 5 and raising the temperature to boil. Unfortunately, ring dyeing of the fibre and yarns was clearly evident and as a result, light fastness reduced by 1-2 points. These drawbacks, however, have been overcome by the use of low molecular weight species and pretreating the cotton fabric using a pad-thermo fixation technique. Another advantage is the need for shorter washing-off process to remove the unfixed dye because of high level of dye-fibre fixation achieved.

In colouration of cellulose fibres, vat dyes (including Indigo) and sulphur dyes hold a large part of the dyestuff market. Vat dyes give excellent fastness, whereas sulphur dyes are economical with good degree of fastness properties. The reduction process employed here requires reducing agents and it has yet not been possible to regenerate these conventional agents, except in the standing dyeing procedure.

In recent investigations, an electrolytic process was used to achieve dye reduction. In direct electrolysis, the dye itself has to be reduced at the surface of the cathode, while in indirect electrolysis the reducing power of the cathode is transferred to the solution by a soluble redox system (mediator). This reversible redox system is continuously regenerated at the cathode so that a renewal of the reducing agent is achieved. This technique offers the possibility of full dye-bath recycling, including the reuse of reducing agents.

Cotton may readily be modified by pretreatment with N-methylolacrylamide to introduce pendant activated double bonds. These have been exploited in two ways to improve the reactive dyeing of cotton. Firstly, by introducing amino residues at these new sites, excellent dyeings with reactive dyes can be achieved at pH 5-7 in absence of an electrolyte, coupled with a very high degree of fixation. Secondly, it is possible to dye the cellulose, modified only with N-methylolacrylamide, with dyes containing pendant aliphatic amino residues. In this case, it is necessary to dye in the presence of an electrolyte under alkaline conditions but very high colour yields are obtained, thanks to the elimination of the hydrolytic side reactions normally associated with reactive dyeing.

Such amino-containing dyes can be readily prepared from all commercial ranges of reactive dyes.

Pretreatment of cotton with polyepichlorhydrin dimethylamine produces a modified cotton that can be dyed under neutral conditions with selected low-reactivity dyes without salt. The dyeings of treated cotton exhibit improved colour yield and high wash fastness. Both exhaust dyeing and continuous dyeing of treated cotton give high colour yield.

Pretreatment of cotton with higher molecular mass polyepichlorhydrin dimethylamine could introduce more cationic sites onto the modified cotton. This would increase the extent of complexing with the dye and thus improve the dyeability with direct and reactive dyes.

Ethylene diamine tetra(methylene phosphonic) acid when adsorbed by cotton fibres prior to the application of the direct dye Solamine Fast Red 4BL causes a marked increase in rate of dyeing. It also improves the wet fastness properties of the dyed cotton.

3.3 Wool Fibres

Due to the increasing environmental problems of dyeing with heavy metal containing dyes as well as with reactive dyes, the dyeing behaviour of plasma treated wool towards these dyes was recently investigated by Hooker and coworkers. Plasma treatment on wool have shown that it leads to, apart from an improvement in the mechanical properties of the fibre, improved dyeability with acid dyes, reactive dyes and metal-containing dyes, and reduced felting tendency. Low-temperature glow discharge treatment of wool opens up the following possibilities to the wool dyer:

- Improved utilization of the existing plant due to reduced dyeing times,
- Savings in cost and maintenance of intensive water purification plants as well as possibilities for recycling the dye effluents due to reduced discharge of toxic components,
- Cost savings by reduction in the amounts of dyes and auxiliaries, and
- Improved market prospects due to environmentally friendly process management.

It has also been observed by Fibre Research Institute, Israel, that wool on treatment with enzymes loses its felting property. At the same time, fibre seems to acquire much enhanced acid dyeability.

3.4 Silk Fibres

As far as the dyeing of silk fibre is concerned, the low-temperature dyeing has been attempted using various redox systems. These systems cause an increase in the number of dyeing sites on the silk, through
Incr ease d reproducibility by
es: conjunction with the application and es tin g in new equipment or improving old machine of design that entails themoves in the right direction. More economical dyeing processes can be achieved cost effectively. At the same time, the finished product must meet the quality demands of the consumer. The introduction of new technology and the modification of design that entails the moves in the right direction. More economical dyeing processes can be achieved in the piece and yarn dye house applying the short and ultra-short liquor technology, liquor flow control and finishing by the Synchron Dyeing System.

In batch piece and yarn dyeing, it is essential that the finisher has machines at his disposal that operate cost effectively. At the same time, the finished product must meet the quality demands of the consumer. The introduction of new technology and the modification of design that entails the moves in the right direction. More economical dyeing processes can be achieved in the piece and yarn dye house applying the short and ultra-short liquor technology, liquor flow control and finishing by the Synchron Dyeing System.

Of course, an increase in productivity and quality is today conceivable without an electronically-controlled process sequence.

It is, therefore, important for the finisher when investing in new equipment or improving old machine plant to get familiar with the latest advancement in dyeing machine manufacture and the latest process technology.

The advent of metering technology has made the short liquor dyeing a reliable process. The modern metering system—Multi-product Injection (MPI)—permits controlled dispensing of solids or liquids such as dyes, salts, alkalis, acids or other textile auxiliaries.

Multi-product Injection (MPI) metering system in conjunction with the application of short and ultra-short liquor technology has the following advantages:

Automation of the dyeing process avoiding incorrect additions of dye solution, auxiliaries and chemicals; moreover, there are no idle times. Reliability of the process, because there is always an optimum reaction medium available for the dyeing process. Increased reproducibility by exact repetition of the dyeing process. Optimization of the levelness. Cost savings by using caustic as fixation alkali instead of soda (e.g., in reactive dyeing). Cost savings by using acid (acetic or formic) in wool polyamide dyeing. Simplification of the rinsing and washing processes in reactive dyeing, owing to less hydrolytization formation during the dyeing process. Often it is possible to reduce the dyeing time. More reliable short liquor dyeing, especially with dark colours. By metering-in the dye, the concentration of dye in the dye bath is reduced so that no precipitation can occur. Increasing automation in application of dyes to the fibre substrate has been one more guiding principle in the development of the machinery as described above. One of the typical examples in exhaust dyeing is ADC-200, a metering device developed by Hoechst and ADCON. The process, more known as Ramazan, automates the supply of alkali for the fixation of the reactive dyes automatically and progressively in order to obtain the highest levelness in shortest dyeing time. The emergence of short liquor jets for dyeing cotton and its blends has been marked over recent years. Not only does this process offer the possibility of more economical dyeing but it also reduces the load inflicted on the environment to the tune of 30% (ref. 29).

On-line controls in continuous dyeing are found to be effective in improving the cost efficiency and reproducibility. For example, on-line liquor pick-up measurement with level correction and control enables precise calculation of the volume of liquor needed and consequently savings in the cost of dyes and auxiliaries. On-line colourimetry of the padded fabric improves the control over the production process with reliability and improved quality.

4.1 Jigger Dyeing

Jigger is the most stable machine in dye house and future dyeing jiggers will have a very modern look and will be characterized with useful aspects which are summarized under “Future Trends” in this paper.

4.2 Jet Dyeing

The utility, specific application and pressure co-
dition inside the vessel as well as the shape of the vessel have been, for quite some time, under constant examination. Some manufacturers have finalized designs for all types of materials and dyes, which claim all the important features such as:
- Dyeing temperatures up to 140°C when desired,
- Soft flow or overflow,
- Low liquor ratio up to 1:5,
- Automatic controls by microprocessors,
- Suitability for light weight as well as heavy fabrics, say 50-500 g/m²,
- High fabric speeds at the lowest possible pressure,
- Tangle-free operation,
- High quality dyeing results with reduced tension and surface abrasion,
- Minimum operator involvement, and
- Economy of energy, water and chemical auxiliary ingredients.

In other words, more air, less liquor and gentle handling have been the key factors behind the development of jet dyeing machines.

Then's Air-Flow ASF machine uses the liquor ratio about 1:2 and it is found to give high productivity and low consumption of water and chemical. The dye solution is automatized with the air stream which is produced by the blower for application on the fabric. The Italian machinery maker 'Laip' has brought out air-water-flow Mod 800, a latest rope dyeing machine, for both knitted and woven fabrics. The air-injection is not simply used to accelerate the fabric to high speed but in some cases to open the fabric. "Apollon Twin Soft Flow" machine manufactured by a Greek machinery manufacturer makes use of microwash system, using clean hot water which is introduced through the double-overflow of the machine to achieve very high cleaning efficiency.

4.3 Continuous Dyeing

The component units of the continuous dyeing ranges are being modified from time to time to minimize the possible imperfections in the final dyed product. Development work regarding these component units is still in progress. The points which have been and which will be considered during such work include:
- Composition and formation of pad rollers,
- Pre-drying by infra-red radiation to avoid possible migration, with vertical fabric passage, and
- Well-designed and evenly impinging hot flue or high-temperature dryers for thermosol dyeing.

With the advent of synthetics and blends, the thermosol system is bound to achieve a very promising position.

The FD 45 pad-stream machine from Ramisch kleinewefers for the continuous dyeing of cotton and its blends with viscose rayon or polyester has been reported. In addition to a Bicollex padding arrangement, the machine has system for feeding in single doses of chemicals and storage programmable control. This control system has a modem which permits continuous dialogue between the supplier and the customer. It could be preferably used for vat and sulphur dyes.

5 Garment Dyeing

5.1 Dyes

Proper selection of dyes and finishing chemicals is quite important for dyeing of garments made of cotton, wool, nylon, polyester, acrylic and their blends. The range of articles include socks, sportswear, shirts, T-shirts, etc. Of the dyes available in the market, reactive dyes are the most popular dyes used in garment dyeing. Newly introduced bireactive dyes are finding increasing application and are preferred to direct dyes. Subsequent treatment with dye fixing agent is also recommended to improve fastness properties. Other dyes used for garment include acid and reactive dyes for woollen garments, cationic dyes for acrylic, and sulphur and vat dyes for cellulosic garments. The chlorine fastness of sulphur and reactive dyes is poor whereas vat dyes have the best performance properties although they are quite expensive.

5.2 Dyeing Methods

Exhaust dyeing is carried out using special dyeing machines for garments.

5.3 Machinery

The most recent development from Gilwood (Fabricators) Co. Ltd, a British machine maker, is an oval, double side-paddle machine for dyeing readymade knitwear. Machine capacity ranges from 150 to 6800 litres. Positive dye penetration is achieved by specially designed paddles fitted with synchronised drive for enhanced liquor circulation. An innovative recirculation system delivers heated liquor simultaneously to the two-paddle area, significantly improving the overall temperature control.
The recent innovation in conventional drum dyeing machine is the one with liquor circulation through the drum centre. This helps imparting an extremely gentle treatment to the goods even at low liquor ratios, i.e. 1:6. This kind of machinery has the advantage of dyeing all kinds of hosiery. The goods dyed can also be centrifuged in the same machine which means investment costs for centrifugers are avoided. The technical advantages include:

- Level dyeing due to rapid liquor interchange.
- Reduced water effluent and less steam and chemical consumption because of operations at low liquor ratios, and
- In-built hydroextraction.

The newer machinery for garment dyeing are based on the following features: (i) Low liquor ratio, (ii) Microprocessors - for improved lot-to-lot reproducibility, (iii) Heat exchangers - for rapid heating and cooling, (iv) Lint filters, (v) Centrifugal hydroextraction, (vi) Easy sampling without dropping dye liquor, (vii) Tilt - for ease of loading unloading, and (viii) Variable drum speed, and (ix) Automatic balancing drum.

What is important in garment dyeing is to achieve level dyeing, with excellent penetration in short dyeing cycle. The developments are thus directed towards these aspects.

6 Microfibre Dyeing

The microfibres are the latest entrant in textile market and have inherent advantages for which their consumption is increasing day by day. However, because the microfibre has increased surface area, the rate of dyeing is tremendously enhanced and it becomes essential to control the dyeing of microfibres to avoid uneven dyeing. The dyings obtained are also apparently lighter as compared to the ones with the normal denier polyester yarn and it is difficult to get the deep shades in microdenier varieties. The fastness to washing, rubbing and light is inferior to that of normal denier polyester. This necessitates the selection of proper range of disperse dyes specially suited for microfibres.

The Foron RD dyes of Sandoz seem to be performing favourably. To improve the lightfastness of the dyed microfibres, use of Fade RF liquid is recommended since this acts as a kind of UV-absorber. A number of dyes manufacturers are making the selection of dyes from the point of view of their application on microfibre fabric.

7 Dyeing of Hosiery/Knits

In dyeing of knitted fabrics, cold brand as well as hot brand reactive dyes and also the direct dyes are used for 100% cellulosic fabrics. The dyeing is carried out in tensionless form in winch and since the winch dyeing machine doesn't allow uniform temperature maintenance, the reactive dyes of HE and ME class are increasingly being preferred.

8 Dyeing of Terry-Towels

The dyeing of terrycloth is more confined to dyeing of yarns which are then subsequently used for producing jacquard designs. The aspects of dyeing and the selection of dyes remain same as in the case of hosiery. However, when no tinting of the ground is expected, the vat dyed yarns are used in manufacture of terrycloths rather than azo, sulphur, reactive and direct dyes.

A two-step dyeing technique is available by which cross-dyeing of 100% cotton terrycloth can be achieved with fibre reactive dyes. The first step involves continuously dyeing of the fabric, using an auxiliary that promotes coloration of the tips of the terrycloth. Subsequent dyeing is carried out in a bath with contrasting colour fibre-reactive dye. An attractive twotoned appearance results.

9 Future Trends

The dye manufacturers would concentrate on research activities to develop new chromophores and dyes offering wider shade gamuts, higher colour fastness, improved environmental impact and higher overall cost efficiency in the colouration process.

In future, the disperse dyes based on benzodifuranones will encourage more research to deal with structural and physical form modifications designed to improve build-up, and also encourage research for new chromogens that are particularly suitable for polyester in general and microfibres in particular.

The future developments in reactive dyes are likely to be concentrated on:

- High application flexibility: A broad spectrum of shades should be dyeable by widely differing application methods with a small number of dyes.
- Good reproducibility and good levelling properties.
- Outstanding protection to environment.
- Maximum productivity.

Apart from these, the dyeing process with dyes containing no reactive group (in the usual sense) but capable of being crosslinked to cellulose via a suitable reagent will find its place in industrial application.

For dyeing cellulosic fibres, high-fastness direct dyes will be selected to avoid use of copper or chromium salts. In reactive dyeing, use of urea will be minimized. For dyeing with sulphur dyes, the highly polluting sodium sulphide will be replaced by other ag-
ents such as reducing byproduct from maize starch industry or hydroxy acetone\textsuperscript{37-38}. For oxidation of vat and sulphur dyes, hydrogen peroxide, sodium perborate and 1, 3-dinitrobenzene sulphonic acid will be used in place of dichromate.

During polyester dyeing, chlorinated or phenolic carriers will be avoided. Acetic acid used for pH adjustment having high BOD will be replaced by other agents.

In case of dyeing machineries, the jiggers of tomorrow will be characterized by the following useful aspects:

- Excellent closing and opening.
- Heated hook for drip-proof working.
- One way flap-opening chimney for releasing unwanted hot and wet flue.
- Internal machine lighting to offer a good view of the fabric under process.
- Pump for recirculating the dye liquor.
- Safety devices and emergency switches for avoiding damage owing to sudden breakdown.
- Automatically controlled drain valve.
- Automatic reversal, delay-relay fabric direction indicator as well as speed indicators.
- Effective crease removing expanders and motorized selvedge aligning and continuous centering system.

Developments in winch dyeing machinery with better temperature distribution and liquor movement are expected, mainly for dyeing knitted fabrics.

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