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SUSTAINABLE AND ENERGY-EFFICIENT DYEING OF HOT BRAND REACTIVE DYES ON COTTON SUBSTRATE

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ABSTRACT - *Energy conservation is the basic requirement in the present scenario when the entire world is facing energy crisis. The chemical wet processing of textiles consumes large amount of energy since most of the processes, including pretreatments, dyeing, printing and finishing are performed at considerably high temperatures. The cost of energy is continuously increasing and is becoming a significant share of the total cost of processing textiles. Among various wet processing operations, the dyeing process consumes more than 50 % of energy. Therefore, it is essential to design various techniques so as to reduce the energy consumption during dyeing. Lowering the temperature during dyeing is one such aspect which substantially minimizes the energy requirements. The present work aims to develop conditions suitable for the application of bis-monochloro–s-triazine (HE, hot brand) reactive dyes, on cotton substrates at low temperatures. The feasibility of reactive dyeing of cotton fabrics with HE reactive dyes at low temperature was carried out in the presence of a swelling agent (tri-ethanolamine) in conjunction with an alkali. Both conventional and swelling agent-assisted dyeings were performed in the presence of the same alkali, viz. sodium carbonate. The colour strength values of the dyed samples were evaluated spectrophotometrically and were compared with conventionally dyed samples. The fastness characteristics, viz. wash, light and rub fastness were also assessed by standard measurement techniques for commercialization of the modified low-temperature dyeing technique.*

Keywords: *hot brand reactive dye, swelling agent, low-temperature dyeing, colour strength, fastness characteristics*

1. INTRODUCTION

Textile wet processing consumes a large amount of energy. These processes involve the use of chemicals for assisting, accelerating or retarding their rates and must be carried out at elevated temperatures to transfer mass from processing liquid medium across to the textile substrate in a reasonable time. The present day scenario in the textile processing calls for the conservation of energy or usage of low amount of energy [1-3].

The dyeing process is regarded as one of the most important parts of textile wet processing, which utilizes very large amounts of energy. In general, dyeing involves adsorption of dye molecules/ions on the fibre surface from the solution phase (i.e. dye-bath), followed by the diffusion of the adsorbed species into the fibre substance, and finally interaction of these species with the fibre substance. These processes are influenced by controlled conditions of pH, temperature, dye concentration, presence of dyeing assistants (viz. leveling or exhausting agents), liquor ratio, etc. Temperature plays a very key role in the economics of the dyeing process. Hence, one of the main objectives of a successful dyer is to reduce the temperature of dyeing in order to conserve energy. Attempts have been made to reduce the energy consumption by performing dyeing at temperatures lower than those utilized in the conventional dyeing process. Several

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literatures are available which specify that the conventional dyeing conditions for textiles can be modified by different techniques, viz. graft polymerization [4, 5], redox systems [6-8], solvent dyeing, etc. [9-14].

The association of dye in aqueous medium also depends on the nature of the additives used. Different types of additives viz. solubilizing agents, swelling agents or carriers, surfactants of various types, high polymeric compounds and hydrotropic substances are commonly employed to facilitate wetting, dispersion, solublisation and/or levelling of the dye during dyeing. These substances help to achieve optimum dyeing results, sometimes even at lower dyeing temperatures. In the present work, a swelling agent, namely tri-ethanolamine (TEA) has been used along with conventional alkali (sodium carbonate) as catalyst to accelerate and promote formation of dye-fibre covalent bond even at lower temperatures so as to achieve improved dye fixation [15]. Bis-(monochloro-s-triazine) based hot brand reactive dyes are generally applied onto cellulosic substrates at about 80^{o} C, but in the presence of a suitable swelling agent like TEA, the dyeing was conducted at lower dyeing temperatures leading to substantial saving of energy.

2. MATERIALS & EXPERIMENTAL PROCEDURES

2.1 Materials

2.1.1. Fabric

Cotton fabric (poplin, 78 g/m^2) with 54 ends/inch and 44 picks/inch was used for this study. The fabric was scoured with 5 g/l non-ionic detergent (Lissapol N) and 5 g/l soda ash at boil for 90 min. After proper washing, the scoured fabric was then bleached with sodium hypochlorite (5 g/l of available chlorine) using pH 10 at room temperature for 1 hour and subsequently washed thoroughly till it became neutral.

2.1.2 Dyestuffs used

The reactive dyes used for study consist of two mono-trichlorotriazine groups and the class is commercially represented as bis (monochloro-s-triazine) or High Exhaust (HE) class of reactive dyes. These dyes are usually applied on cotton and other cellulosic fibres at 80^{o} C temperature and are fixed on to the substrate in presence of alkali, sodium carbonate or sodium bicarbonate. The specifications of various commercial bis (mono-s-trichlorotriazine) reactive dyes used for the work are given in Table 1. The dyes were selected to produce three primary shades from textile dyer’s point of view. These dyes were used without any further purification.

2.1.3 Chemicals and auxiliaries

Tri-ethanolamine is used as the swelling agent for cotton to assist low temperature dyeing of reactive dyes while sodium carbonate (soda ash) is used in the dyeing liquors for the fixation of reactive dyes on to the cotton substrate. Glauber’s salt is used as an exhausting agent for the exhaustion of the reactive dye from the dyebath to the cotton fibre. The swelling agent, Tri-ethanolamine, and the other chemicals namely, sodium carbonate and Glauber’s salt used for the present work were of Laboratory Reagent grade.

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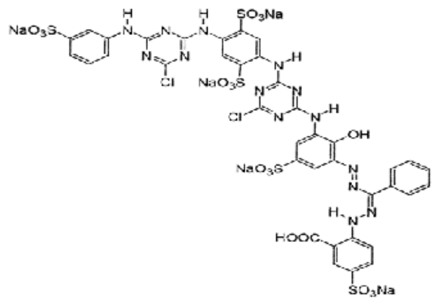
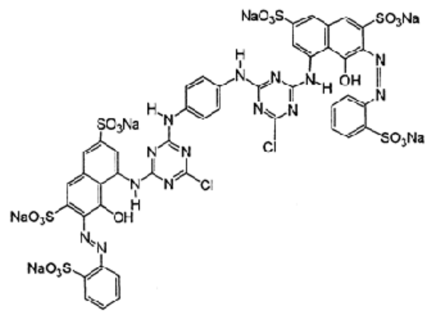
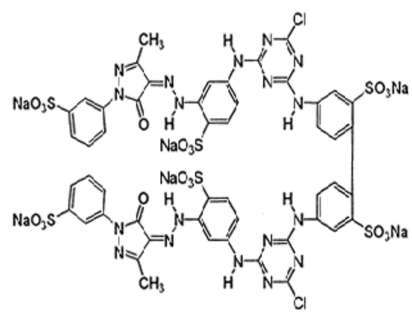
Table 1: Characteristics of commercial reactive dyes

Reactive dye	Colour Index Number (C.I. No.)	Chemical structure	Molecular formula (molecular weight)
D I Reactive Blue HERD	CI Reactive Blue 160		$C_{38}H_{23}Cl_2N_{14}Na_5O_{18}S_5$ (1309.86)
D II Reactive Red HE-3B	CI Reactive Red 120		$C_{44}H_{24}Cl_2N_{14}Na_6O_{20}S_6$ (1469.98)
D III Reactive Yellow HE-4G	CI Reactive Yellow 105		$C_{50}H_{32}Cl_2N_{18}Na_6O_{20}S_6$ (1606.14)

2.2 Experimental methods

2.2.1 Dyeing procedures

The dye-baths prepared for conventional dyeing method and solvent-assisted low temperature dyeing method are depicted as Bath I and Bath II in Table 2.

Table 2. Recipes for different dye-baths

Dye and Chemicals	Bath I (%)	Bath II (%)
Reactive dye	2	2
Soda ash	2	2
Tri-ethanol amine	--	1, 3 & 5
Glauber's salt	10	10

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The material to liquor ratio of each of these baths was maintained at 1:30. The dyeing was performed on Laboratory Constant temperature water bath. The scoured and bleached cotton fabric sample was entered in each of these baths at room temperature.

- *Conventional dyeing:* The Bath I is for conventional dyeing of reactive dyes in which TEA is not added. The temperature of this bath is slowly raised to 80^o C and dyeing continued at this temperature for about 60 minutes.
- *Modified dyeing at low temperatures:* The dyeings are carried out using various concentration of TEA (1%, 3% and 5%) at various temperatures such as room temperature (30^o C), 40^o C, 50^o C, and 60^o C. These dyeings were conducted in presence of sodium carbonate, as a fixing agent, as in the conventional dyeing process.

2.2.2 Testing and Analysis

- *Evaluation of Colour Strength:* Instrumental colour evaluation of the conditioned dyed samples was carried out using a spectrophotometer with 10° observer using D65 illuminant. An average of three measurements of colour strength (*K/S*) or reflectance was recorded. The colour measurement was done by Spectrophotometer inter-phased with computer colour matching system; Spectra scan 5100 (RT) (Premier Colour-scan instrument), India. Colour measurement is based on the ratio between total light absorbed (*K*) and scattered (*S*) by the substrate as defined by the Kubelka-Munk equation:

$$K/S = (1 - R)^2/2R$$

where, K = absorption coefficient,
S = scattering coefficient,
R = reflectance measured at a given wavelength.

The *K/S* value is commonly used as a basis for evaluating the dye build-up or change in colour strength. Comparison of colour strength can be made based either on the reflectance values at maximum absorption wavelength (λ_{max}) or on the sum of reflectance values across the visible spectrum when no specific peaks are identifiable. Any particular colour may be represented by a graph of the *K/S* or reflectance values (across the visible spectrum) plotted against corresponding wavelength [16].

- *Assessment of Fastness Properties* [17]: Wash fastness was evaluated according to ISO Standard Test No.3 on Launder-o-meter; light fastness on Fade-o-meter using xenon-arc continuous illumination (BS 1006: 1987) and rub fastness (both dry as well as wet) on Crockmeter (BS 1006: No.X12; 1978).

    - *Fastness to washing:* Wash fastness of different dyed samples was assessed on Launder-o-meter using ISO standard Test No. 3. A specimen is cut in 4 cm × 10 cm size. A solution containing 5 g/l soap solution and 2 g/l soda ash was used as the washing liquor. The samples were treated for 45 minute at 60°C using material to liquor ratio of 1:50. After rinsing and drying, the change in shade was visualized using Grey scale and graded from 1 to 5; where 1 indicates poor and 5 excellent fastness to washing.

    - *Fastness to Light:* This test method provides the general principles and procedures which are currently in use for determining the colour-fastness of textile materials to light.

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Fabric Specimen - Cut swatches of fabric with the long direction parallel to the machine (warp) direction, at least 70.0 mm × 120.0 mm with the exposed area measuring not less than 30.0 mm × 30.0 mm. The sample under test and a set of blue wool reference standards are arranged on a suitable backing card. The half of the strips is covered with opaque card. The framed test material is then mounted on the specimen rack. All materials are adequately supported, both top and bottom, in proper alignment. Any displacement of the material toward or away from the source, even by a small distance, may lead to variation in fading between specimens. The assembly is then exposed to xenon arc lamp light for 8 hours. When the cards are removed, the specimen and standards will show areas that have been exposed to light and unexposed to light. Rate the amount of colour change in exposed area under examination by means of the Gray Scale for colour change and appropriate grades are given from 1 to 8, where 1 stands for poor and 5 represents excellent light fastness.

- *Fastness to Rubbing:* Fastness to rubbing is used to ensure that fabrics do not transfer their colour when rubbed against another layer of fabric. The rub fastness of dyed samples was tested on Crockmeter. A crockmeter is a piece of equipment that applies a constant force on the test fabric against the tested specimen as it is rubbed back and forth. The specimen to be tested was rubbed against perfectly scoured and bleached cloth of dimension not less than 22 cm x 5 cm. The white rubbing cloth was placed over the end of the finger of the testing device. In the dry rubbing test, the cloth to be tested was rubbed 10 times in 10 sec. in dry state; while in the wet rubbing test, the procedure was same, except that the rubbing cloth was wetted out and squeezed to 100 % expression. The grading was given by taking into consideration the intensity of stain obtained on white fabric as well as lowering in the depth of the rubbed sample. The staining on the rubbing cloth was assessed with the Grey Scale and grades awarded from 1 to 5 (1 stands for poor and 5 for excellent fastness to rubbing).

3. RESULTS AND DISCUSSION

The main objective of this study is to accelerate and enhance the dyeability of cotton fabrics with hot brand bis (monochloro-s-triazine) reactive dyes even at low temperatures. To achieve this, an attempt has been made to incorporate a suitable swelling agent namely tri-ethanolamine (TEA), for cellulosic substrate, in the dyeing formulation under a variety of conditions. Variables studied include the concentration of TEA, dyeing temperature, reactive dyes of different shades and hues. Three different concentrations of TEA were used, namely 1 %, 3 % and 5 %; while the dyeing was performed at different temperatures, namely room temperature (30^o C), 40^o C, 50^o C and 60^o C. Reactive dyestuffs selected were Reactive Red HE-3B, Reactive Blue HERD and Reactive Yellow HE-4G; and the alkali used for fixation of reactive dyes by conventional as well as modified low-temperature dyeing methods was sodium carbonate. The time of treatment was kept fixed for 60 min and the liquor ratio was maintained at 30:1.

3.1 Effect of concentration of TEA on dyeing performance of bis (monochloro-s-triazine) reactive dyes

Table 3 represents the effect of the concentration of TEA on the colour strength values, expressed in terms of *K/S* values, for the cotton substrates, dyed 2% shade with Reactive Red HE-3B, Reactive Blue HERD and Reactive Yellow HE-4G hot brand reactive dyes, in the presence of sodium carbonate, at different dyeing temperatures. The table also indicates the colour strength values for cotton samples dyed conventionally at 80^o C in absence of TEA. From the table, it is clear that when the concentration of TEA

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is increased from 1% to 3%, there is considerable increase in the *K/S* values at almost all dyeing temperatures. However, in most of the cases, the colour strength values are nearly same at 3% and 5% concentration of TEA; in some cases the values are marginally higher for 3% TEA as compared to 5% TEA. This indicates that the concentration of TEA must be optimized whenever a particular low dyeing temperature is selected for the application of a particular hot brand bis-MCT reactive dye. This enhancement in the colour strength could be associated with the favourable effect of TEA on

- enhancing the swellability and accessibility of the cellulose structure,
- modifying the state of the dye as well the dye structure, thereby enhancing the reactivity, and/or
- increasing the extent of dye-fibre covalent bond fixation, thereby increasing *K/S* values. The increase in TEA concentration up to 5% for a given set of dyeing conditions has practically no significant effect on spectral values and in some cases the *K/S* value decreases.

Table 3. Colour strength (*K/S*) values of bis-MCT reactive dyes dyed by conventional and modified low temperature dyeing methods

Dye	Temp. (^{o} C)	Colour strength (*K/S*) values for bis-MCT Reactive dyes dyed on cotton using different concentrations of TEA (%)			
		--	1	3	5
D I	R.T.	--	4.32	5.84	6.17
	40	--	5.67	7.13	7.48
	50	--	6.89	7.68	7.95
	60	--	6.42	7.57	7.23
	80	6.98	--	--	--
D II	R.T.	--	9.73	10.21	10.92
	40	--	10.33	11.24	11.11
	50	--	11.79	12.92	12.26
	60	--	11.56	12.87	12.32
	80	11.43	--	--	--
D III	R.T.	--	3.29	4.17	4.01
	40	--	4.11	4.83	4.86
	50	--	4.89	5.78	5.54
	60	--	4.76	5.62	5.33
	80	4.63	--	--	--

3.2 Effect of temperature on dyeing performance of bis-(monochloro-s-triazine) reactive dyes

The effect of dyeing temperatures on the colour strength of cotton fabric dyed with bis-MCT reactive dyes can be also visualized from the Table 3. It can be clearly seen that within the selected dyeing temperature range, i.e. 30^o C to 60^o C; for low temperature dyeing, the increase in dyeing temperature is accompanied by a rapid and significant increase in dye fixation in the beginning up to 50^o C, after which there is not much significant increase in the dye uptake. The raising of dyeing temperature appears to result in

- opening up of the cellulose structure,
- increasing the accessibility of cellulose hydrolysis,

- enhancing the mobility as well as reactivity of dye molecule in the presence of TEA, and
- overcoming the activation energy barrier of the dyeing process, thereby increasing the level of molecular activity of the dye-fibre system as well as the dye-fibre interaction.

The study reveals that the optimum temperature, which could be best selected for the commercialization of this modified dyeing process in presence of TEA, is 50^o C.

3.3 Fastness characteristics of dyed samples

Various fastness properties viz. wash, light and rub (dry as well as wet) were assessed by standard analytical procedure and samples were graded accordingly. It has been found that the cotton fabrics dyed with bis-MCT reactive dyes at low temperature have shown very good to excellent fastness grades and the results are quite comparable with those of conventionally dyed samples at 80^o C.

Table 4. Various fastness grades for bis-MCT reactive dyes dyed by conventional and modified low temperature dyeing methods

Dye	Temp. (^{o} C)	Fastness grades for bis-MCT reactive dyes dyed on cotton using different concentrations of TEA (%)															
		W	L	R		W	L	R		W	L	R		W	L	R	
				Dry	Wet			Dry	Wet			Dry	Wet			Dry	Wet
D I	R.T.	--	--	--	--	3-4	6	3	3-4	3	5-6	4	3-4	4	5-6	4	3-4
	40	--	--	--	--	3-4	6-7	4	3-4	3-4	5-6	4-5	3	4-5	5-6	4-5	4
	50	--	--	--	--	4-5	7	4-5	5	4-5	7-8	5	4	4-5	7	4-5	4-5
	60	--	--	--	--	4-5	7	4-5	4-5	4-5	7	4-5	4	4-5	6-7	4-5	4-5
	80 (Control)	4	6-7	5	4	--	--	--	--	--	--	--	--	--	--	--	--
D II	R.T.	--	--	--	--	3	6	3-4	3	3-4	5-6	4-5	3-4	4	5-6	4	3-4
	40	--	--	--	--	4	7	4-5	3-4	3-4	6	4-5	3-4	4-5	6	5	4-5
	50	--	--	--	--	4	7	4-5	4-5	5	7	4-5	4-5	4-5	7	4-5	4-5
	60	--	--	--	--	4-5	6-7	4-5	4-5	4-5	7	4-5	4	4-5	6	4-5	4-5
	80 (Control)	4-5	7	4-5	4-5	--	--	--	--	--	--	--	--	--	--	--	--
D III	R.T.	--	--	--	--	3-4	6	3	3-4	3	5-6	4	3-4	4	5-6	4	3-4
	40	--	--	--	--	3-4	6	4-5	3	4	5-6	4-5	3-4	4-5	5-6	4-5	4
	50	--	--	--	--	5	7	4-5	5	5	7	5	4-5	5	7-8	5	5
	60	--	--	--	--	4-5	6-7	4-5	4-5	4-5	7	5	4-5	4-5	6-7	4-5	5
	80 (Control)	5	6-7	4	4-5	--	--	--	--	--	--	--	--	--	--	--	--

4. CONCLUSIONS

The application of hot brand bis-(monochloro-s-triazine) based reactive dyes can be successfully performed on cotton (cellulosic) substrates in the presence of a swelling agent, namely tri-ethanolamine, at low temperatures leading to considerable saving of energy. The shades obtained with the modified dyeing were uniform and some of the results were even better than those of the samples dyed by conventional dyeing method at 80^o C. The dyeing performance was enhanced by the utilization of alkali, which acts as an accelerator and fixing agent. The fastness characteristics were adequate and comparable with conventionally dyed samples. The incorporation of swelling agent in the dyeing liquors will thus enable the dyer to perform dyeing at much lower temperatures, making the process economical and energy-efficient.

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