Dyeing of Polyester Woven Fabric with Disperse Dye Using Conventional and Microwave Technique

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ABSTRACT

Polyester fabric is generally dyed using high temperature dyeing technique and carrier. Both techniques require high energy consumption while few carriers are toxic in nature. In this study, 100% polyester woven fabric was dyed by microwave and conventional dyeing technique with disperse dye; Foron Blue RD GLN by an exhaust method for short dyeing cycle (15 and 30 min). The fabric samples were dyed using conventional high temperature dyeing technique with recommended recipe. Moreover, samples were also dyed using microwave technique with recommended recipe and by the addition of salt and urea, pre-treatment with caustic and organic solvent for improving the dye uptake value and fastness properties. The dyeing assessment; $(K/S)_{\lambda max}$ value by Datacolor spectrophotometer, dye uniformity by optical microscope and washing fastness by grey scale were measured. It has been observed that over conventional dyeing method, microwave irradiation dyed sample gives almost 70% high $(K/S)_{\lambda max}$ value and uniform dye penetration and good to very good washing fastness property. In addition, microwave dyeing gives excellent dyeing behavior at short dyeing cycle; 15 min; hence saves energy and sustainable dyeing process.

Key Words: **Foron Blue RD GLN, Organic Solvent, Causticization, Exhaust Dyeing.**

1. INTRODUCTION

By 2020, the production rate of polyester fibers is going to increase 2.5 times than the natural cotton fibers. This is because of polyester fiber properties such as wrinkle resistance, chemical resistance, tensile strength and durability. It is used in various applications such as apparel, bed sheets, carpets and curtains [1]. However, polyester fibers have few undesirable properties; due to high crystalline fiber microstructure and absence of reactive sites. It is hard to dye the polyester fibers with synthetic dyes such as disperse dyes. The dyeing process is used to be carried out either at high temperature or with carrier. For the optimizing and improving the dyeing behaviour of polyester fibers, many researchers tried to develop different techniques including microwave irradiation [2-4].

The use of industrial microwave improves the working conditions and eliminates the environmental permits by avoiding the combustible gaseous by-products. Hence, it reduces the energy cost, gives fast, effectives and uniform heating over conventional heating system. It has been observed that microwave irradiation was used in different processes of textile. The degumming of raw silk fabric was followed by microwave irradiation. The pad-batch wool dyeing process using microwave irradiation was minimized the dyeing cycle [5]. Moreover, microwave irradiation based steaming

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chamber was designed by Japanese [6]. This irradiation improved the dye exhaustion and migration rate. When polyester fabric was hydrolysed with 1-5% w/w caustic soda using microwave irradiation and then dyed using conventional dyeing technique. It was observed that fabric weight was lowered and wicking property and dye up-take value were increased with the caustic percentage [7,8]. Moreover, pre-treatment of polyester fabric with tetrachloroethylene at boiling temperature for 2-15 min and then dyeing with CI Disperse Brown 1 and Red 65 and Matexil CA, carrier, using microwave irradiation increased the dye uptake while insignificant change was observed in wash fastness properties [2]. Researchers were manufactured the synthetic dyes with microwave irradiation [9,10]. In addition, it has been examined that polyester fabric was dyed using microwave techniques but using carrier only and researchers self-manufactured disperse dyes. However, dyeing with commercial disperse dyes using high temperature exhaust microwave technique is not carried out yet. Therefore, the present study is based on applying the commercial disperse dyes; Foron Blue RD GLN (1% owf) using microwave irradiation. The dyeing was carried out using conventional HT (high temperature) method, microwave technique at different dyeing cycle, addition of salt and urea and pre-treatment with organic solvent and caustic. After dyeing, fabric assessments such as colour strength, washing fastness and dye uniformity were measured and compared with the conventional HT dyeing method.

2. MATERIAL

100% polyester fabric was kindly supplied by Synergies Sourcing Pvt. Karachi, Pakistan. Disperse dye, Foron Blue RD GLN and other dyeing auxiliaries such as dispersing agent, Lyocol RDN, leveling agent, Opticid DSB, and stabilizer, Eganal RAP were supplied by Archroma, Karachi, Pakistan.

3. METHODS

3.1 Conventional Dyeing

100% polyester woven fabric samples (H1 and H2) of 5 gm were taken and dyed with Foron Blue RD GLN (1% owf) using conventional dyeing method on Rapid HT dyeing machine. The dyeing recipe and procedure (temperature and time) is shown in Table 1. The process was carried out at liquor to goods ratio of 20:1 at 80°C with auxiliaries such as Lyocol RDN, Opticid DSB, Eganal RAP for 3 and 5 min. After fabric treatment with auxiliaries, dye liquor was added. For carrying out of dye takeup the temperature was raised up to 130°C and fabric was treated for next 12 and 15 min. After dyeing, the samples were taken out and washed with hot water and then cold water for 10 min each. At last, polyester fabric samples were dried in an oven.

3.2 Microwave Dyeing

The polyester fabric samples were dyed with Foron Blue RD GLN (1% owf) using microwave dyeing techniques. For optimizing the dyeing behavior of microwave dyed fabric; the dyeing process was carried out using following methods.

1. Recommended method.
2. Addition of urea and salt in dye recipe.
   - Pre-treatment with caustic and then dyeing.
   - Pre-treatment with organic solvent and then dyeing.

3.2.1 Recommended Method

100% polyester fabric samples (M_1 and M_2) of 5gm were taken and dyed using radcure, microwave technique with liquor to goods ratio of 80:1. The samples were treated with dye auxiliaries for 3 and 5 min at 80°C and then dye was added. Temperature was increased to 130°C for further treatment of samples, 12 and 25 min. The samples were washed with hot and cold water for 10 min each and then dried in an oven.

3.2.2 Addition of Urea and Salt

For optimizing the polyester fabric dyeing behavior, fabric samples (U1, U2, U3, U4, U5) of 5gm were taken and dyed with recommended recipe along with

TABLE 1. DYEING RECIPE AND PROCEDURE OF FORON BLUE RD GLN BY CONVENTIONAL DYEING METHOD

Sample Code	Shade (%)	Lyocol RDN (g/l)	Opticid DSB (g/l)	Eganal RAP (g/l)	Temperature (°C)	Time (min)
H1	1	1	1	2.5	80-130	15
H2	1	1	1	2.5	80-130	30

various concentration of salt (15-25 gl^{-1}) and urea (10-20% owf) as shown in Table 2. The samples were treated with dye auxiliaries at 80°C. Then, disperse dye was added and temperature was raised to 130°C. The samples were dyed for 15 and 30 min exhaustion and fixation phases. After dyeing; samples were washed with the same method as discussed in preceding Section 3.2.1.

3.2.2.1 Pre-Treatment with Sodium Hydroxide

The fabric samples (C1) was causticized with sodium hydroxide (5% owf) at 100°C for 15 min using microwave irradiation. The causticized fabric after washing was dyed according the recipe as shown in Table 2 and dyeing method as discussed in Section 3.2.2.

3.2.2.2 Pre-Treatment with Organic Solvent

Fabric samples S1 and S2 were pre-treated using Acetone and Dimethylformaldehyde (10% owf) at 60°C for 2 min and then dyed using microwave technique for 15 and 30 min (Table 2) with the same method as discussed in Section 3.2.2. The dyed samples were then rinsed with hot and cold water for 10 min each and at last dried in an oven.

3.3 Assessment

Fastness to washing test was performed according to the British standard BS ISO-105 CO2. After washing, fabric samples were assessed using grey scale and staining scale. The grey scale was used for assessing the change in shade and staining scale for change in multi fiber strips.

Uniformity of dyeing was assessed using Motic video microscope. Firstly, 7-10 dyed yarns were taken from the fabric sample and were laid parallel [11]. The bunch of dyed yarn was then crossed from the hole (app 1 mm dia) of the slide. The extra dyed yarns on both sides of slides were then cut using sharp blade. The prepared slide was then placed on the stage of optical microscope. The microscope was set at constant intensity of light and magnification. The cross-sectional images of yarns were then captured and analyzed visually.

4. RESULTS AND DISCUSSION

4.1 Color Strength

4.1.1 Conventional HT Dyeing

When 100% polyester woven fabric samples (H1 and H2) were dyed by conventional dyeing technique with the recipe as discussed in Table 1. It has been observed

TABLE 2. DYEING RECIPE AND PROCEDURE OF FORON BLUE RD GLN BY MICROWAVE DYEING METHOD

Sample Code	Recipe						Pre-Treatment		Method	
	Shade (%)	Lyocol RDN (g/l)	Opticid DSB (g/l)	Eganal RAP (g/l)	Salt (g/l)	Urea (% w/w)	NaoH (% w/w)	Organic Solvent (% w/w)	Temperature (°C)	Time (min)
M1	1	1	1	2.5	-	-	-	-	80-130	15
M2	1	1	1	2.5	-	-	-	-	80-130	30
U1	1	1	1	2.5	15	10	-	-	80-130	15
U2	1	1	1	2.5		20	-	-	80-130	15
U3	1	1	1	2.5	25	10	-	-	80-130	15
U4	1	1	1	2.5		20	-	-	80-130	15
U5	1	1	1	2.5	15	10	-	-	80-130	30
S1	1	1	1	2.5	15	10	-	10	80-130	15
S2	1	1	1	2.5	15	10	-	10	80-130	30
C1	1	1	1	2.5	15	10	5	-	80-130	15

that the color strength value increases with the dyeing time as shows in Fig. 1. The polyester fabric sample dyed with 30 min dyeing cycle has greater $(K/S)_{\lambda max}$ value (7.1) and the sample (H1) with 15 min dyeing cycle has less $(K/S)_{\lambda max}$ value (5.57). This is because high dyeing time increases the dye molecules diffusion into the fibre Filament of polyester fabric.

4.1.2 Microwave Dyeing

Polyester woven fabric sample was dyed by microwave dyeing technique with recommended recipe prescribed by the Archroma. It has been found that fabric sample dyed using lower dyeing time, i.e. 15 min, gives high color strength value as compared to 30 min dyeing time as shown in Fig. 2. It might be because of longer dyeing time, intensity of microwave irradiation is very high, and the excess energy cause the dye liquor to evaporate with water [7] and less dye molecules are in the liquor. Hence, optimize dyeing cycle for dyeing 100% polyester fabric with Foron Blue RD GLN (1% owf) by microwave exhaust technique is 15 min.

Moreover, colour strength value of polyester dyed fabric by conventional HT (High Temperature) dyeing technique is lower than the microwave technique as shown in Figs. 1-2. The colour strength value of 15 min dyeing time by microwave technique is almost 50% higher than the conventional HT dyeing technique (15 min). Hence, in microwave dyeing technique, the dyeing time is inversely proportional to the colour strength value.

4.1.2.1 Addition of Urea and Salt

Polyester woven fabric samples were dyed by Microwave technique using recommended recipe along with the addition of salt and urea of various concentrations. It is clear from Fig. 3, the addition of salt and urea improves the color strength value of polyester fabric. Again 30 min dyeing cycle decreased the colour strength value. The addition of salt increases the dye exhaustion rate during dyeing process. Whereas, urea gives the moisture contents and enhance the dye polarity during dyeing process. It has been found that addition of urea (20% w/w) gives highest color strength value compared to the other concentration of urea and salt. However, urea of much quantity is unsustainable, therefore, urea and salt of minimum quantity (10% w/w and $15gl^{-1}$) is more appropriate and might have less potential effect on environment.

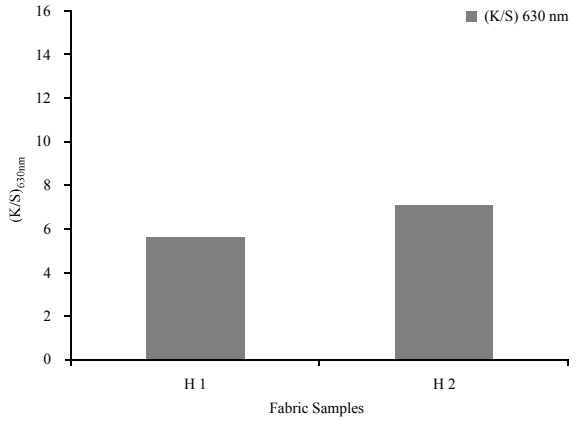

FIG 1. $(K/S)_{630NM}$ VALUE OF CONVENTIONAL DYED FABRIC

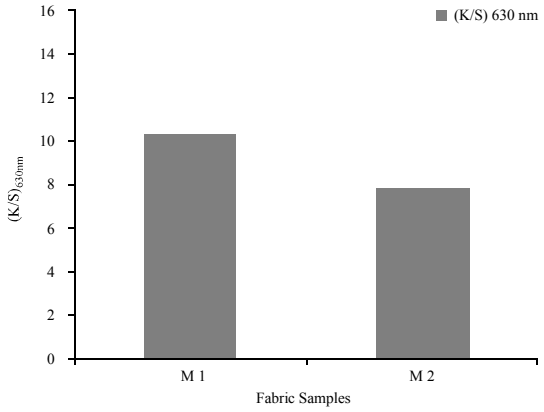

FIG. 2. $(K/S)_{630NM}$ OF MICROWAVE DYEING TECHNIQUE

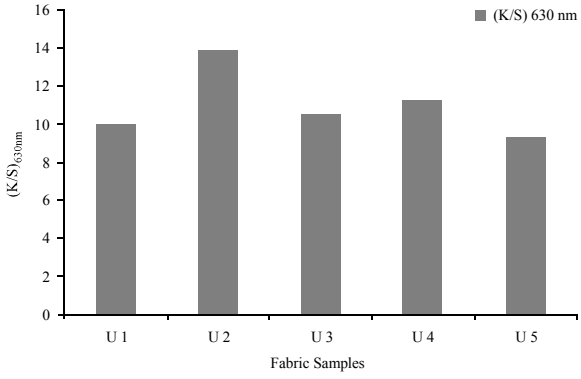

FIG. 3. COLOUR STRENGTH VALUE OF POLYESTER FABRIC WITH THE ADDITION OF SALT AND UREA

4.1.2.1.1 Pre-Treatment with Caustic and Organic Solvent

Polyester fabric samples were pre-treated using organic solvent and sodium hydroxide and then dyed with the recommended recipe along with the addition of urea and salt as shown in Fig. 4. The fabric dyed by caustic soda gives highest colour strength value as compared to the pre-treatment using organic solvent, when dyed by microwave technique using 15 min dyeing time. The pre-treatment using organic solvent allows the dye molecules to diffuse into the fibre of the polyester fabric. Whereas, caustic soda increases the fiber surface area, allows more dye molecule to fix into the fiber of the fabric [12]. In microwave irradiation the dye molecules directly absorb the radiation energy thus increase the dye diffusion due to the fast transfer of heat energy. Compare 15-30 min, again 15 min dyeing time gives high colour strength value.

4.2 Washing Fastness

It has been found that the washing fastness results showed greater difference from $(K/S)_{\lambda max}$ as shown in Table 3. The samples H1 and H2 give the excellent washing fastness properties. However the washing fastness of samples S1 and S2 have good fastness value over microwave dyed samples, it can be optimized that addition of organic solvent in the dye liquor increase the washing fastness.

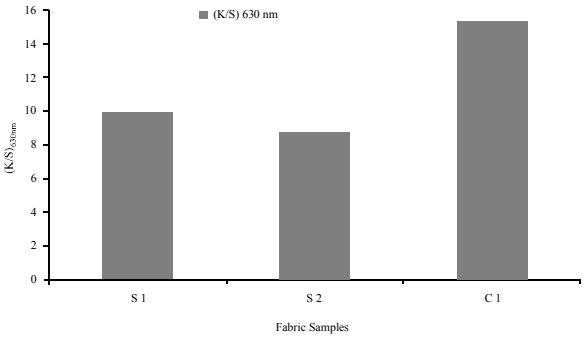

FIG 4. PRE-TREATMENT AND DYEING OF POLYESTER FABRIC WITH FORON BLUE RD GLN

4.3 Dye Uniformity

It is clear from Fig. 5(a-b), the sample dyed by conventional dyeing technique for 30 min have much uniform dye diffusion compared to 15 min dyeing time. On the contrary, it has been observed that when polyester fabric samples were dyed for 30 min; the fiber filaments in center of the yarn of the woven are undyed (more white), hence non-uniform dyeing. It might be because at much higher time dye liquor is evaporated and gives un even dye shade and more dye molecules are on the fabric surface. Similar results have been observed when fabric samples were dyed

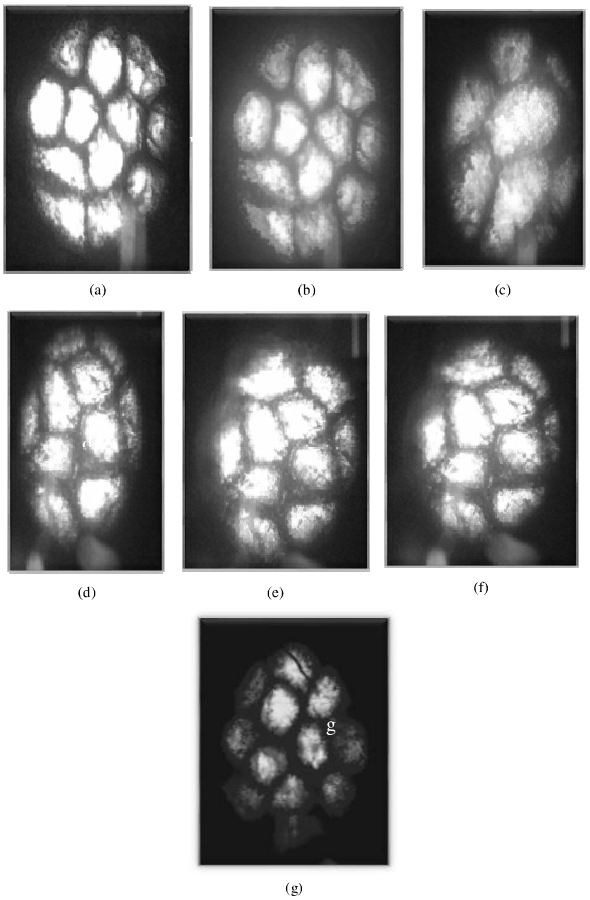

FIG. 5. UNIFORMITY OF FIBER FILAMENT OF THE POLYESTER DYED FABRIC WITH FORON BLUE RD GLN

TABLE 3. FASTNESS TO WASHING OF FORON BLUE RD GLN DYED FABRIC

Sample Code	H1	H2	M1	M2	U1	U2	U3	U4	U5	S1	S2	C1
Staining	4/5	4	2/3	2/3	3	3	3	3	3	4/5	3/4	4/5
Change in Shade	4/5	4/5	4	3	3	3	3	3	3	4/5	3/4	4/5

with the addition of salt and urea at various concentrations. However, organic solvent addition in the dyeing procedure gives much even diffusion of dye molecules as well as high dye uptake. As the dye molecules are more penetrated into the fibre filament and less are remained on fabric surface that is why gives good to very good wash fastness properties. Similarly, caustic soda pre-treatment also gives uniform penetration of dye molecules.

5. CONCLUSIONS

100% polyester fabric was dyed using Foron Blue RD GLN (1% owf) by conventional and microwave dyeing techniques. It is concluded that the microwave dyeing technique gives the high $(K/S)\lambda_{max}$ value even 15 min dyeing cycle compared to conventional HT dyeing method. The highest colour strength value is achieved by caustic (5% w/w) pre-treatment and then dyeing with recommended recipe along with the addition of salt and urea.

The conventional HT dyed fabric samples have uniform dye penetration into the fibre of the polyester fabric. However, samples dyed by recommended recipe using microwave technique have few undyed fibres in the center of the yarn of the fabric. Moreover, conventional HT dyeing gives very good washing fastness results than microwave dyeing technique. However, the washing fastness and dye uniformity of polyester fabric dyed by microwave technique has been improved by the pre-treatment of organic solvent and caustic and addition of salt and urea in the dye liquor.

Hence, microwave dyeing technique saves the time and energy but it requires addition of polar solvents and caustic treatment with definite amount in order to improve the dyeing behavior.

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