Ahmet Çay,
Rıza Atav,
Kerim Duran

Ege University
Department of Textile Engineering,
Izmir, Turkey
E-mail: ahmet.cay@ege.edu.tr

Effects of Warp-Weft Density Variation and Fabric Porosity of the Cotton Fabrics on their Colour in Reactive Dyeing

Abstract
One of the main problems in dyehouses is caused by the differences between the structural parameters of the reference fabric of which the dyeing recipe is known and the fabric to be dyed. In such a case, knowledge of the effects of the parameters such as warp and weft density and fabric porosity on the colour efficiency is of great importance for 'right-first-time' dyeing. Cotton fabrics with different warp & weft densities and porosities were dyed with reactive dyes, and the colour measurements were carried out with a spectral photometer. Warp & weft densities and porosity do not have any evident effect on the colour shade, although a considerable change in colour yield was determined.

Key words: *weft-warp density, porosity, reactive dyeing, 'right-first-time dyeing', colour yield.*

Introduction

Recently, ecological, economical and punctual delivery criteria have acquired great importance in the dyeing process, in parallel with both quality concepts and consumer expectations. Shade reproducibility and level dyeing are the major obstacles in 'right-first-time' production, which has become a basic aim of textile dyers in order to increase their success on the textile market. One-third of the dyes used for cellulose fibres today are reactive dyes [1], due to better features such as higher fastness properties, brighter colour effects, and a wider colour palette. The range of available reactive dyes is wide, and enables a large number of dyeing techniques to be used [1], and over 60% of reactive dyes are applied by the exhaust dyeing method [2].

In practice, dyeing conditions are rarely constant, and this leads to 5-10% of total production being dyed inaccurately. These faults generally occur due to variations in fabric construction, quality and mass; deviations in the liquor ratio, temperature and dyeing pH [3]. When the dyeing performance of a company which uses the exhaust dyeing method and the acceptable limit value of ΔE is 1.2 is investigated, it can be seen that 0.3 of the ΔE comes from dyestuff, but more importantly 0.9 of the ΔE is based on the differences in the material to be dyed and the dyeing conditions [4, 5].

The main problem in dyehouses is caused by the differences between the structural parameters of the reference fabric of which the dyeing recipe is known and the fabric to be dyed. Fabric structure differences would lead to different liquor flow interactions through the fabrics. In such a case, if the dyeing recipe of a loose fabric applied to a dense fabric, the final colour obtained would be different. It is important to recognise the effects of the fabric structure on the colour effects. In this way, correction of the dyeing recipes on the basis of experience and colour measurement results would increase the chances of 'right-first-time' dyeing.

Fluid flow through textiles is a complex physical phenomenon, because of the fibrous and highly non-uniform organisation of the structure and deformation. Nevertheless, fluid flow through a fabric is important in order to understand many of its physical and mechanical properties. Since textiles are discontinuous materials, which are produced from macroscopic sub-elements such as fibres and filaments, they have void spaces or pores, and therefore finite porosities [6]. Critical fabric functionalities, such as the performance of parachute and sailcloth, efficiency of filtration, transportation of the moisture from body to environment, apparel comfort, thermal insulation properties, the rate of liquid penetration during wet processing and liquid removal during drying of fabrics, etc. depend on the porosity of the textiles. Bhattacharjee et al. concluded that a knowledge of porosity makes it possible to determine both the air and water flow through fabrics [7]. In a fabric, pores are situated in the fibres, between fibres in the yarns, and between yarns in the fabric [8]. When considering the fluid flow through textiles, the shape arrangement and size distribution of voids through which the fluid flows are of great importance [9, 10]. It is obvious that the smaller the pore dimensions, the greater the resistance to the dye liquor flow. Therefore, decreased porosity leads to a decrease in the fluid volume passing through the fabric.

The yarn diameter, surface formation techniques, and number of yarn threads per unit area are the main factors affecting the porosity of textiles. Dimensions of the pores are smaller when the fabrics are processed in a wet medium due to the swelling of fibres (especially for hydrophilic natural fibres). It is obvious that porosity is a function of fabric geometry [11]. Porosity is defined as the ratio of the projected geometrical area of the opening across the material to the total area of the material:

$$\varepsilon = \frac{open\ pore\ area}{total\ area} = \frac{P_1 . P_2}{(P_1 + d_1)(P_2 + d_2)} \quad (1)$$

where ε denotes fabric porosity, P_1 the distance between warp threads, $P_2$the distance between weft threads, d_1 the diameter of the warp yarn, and d_2 the diameter of the weft yarn. This calculation is the geometrical expression of porosity, but gives only the inter-yarn porosity of the fabrics. Porosity is defined as the

Table 1. Fabric properties.

Sample no	Warp density, threads/cm	Weft density, threads/cm	Porosity, %	Pore area, mm^2
1	60	20	0,73	1,45
2	60	30	0.67	0.78
3	60	40	0.61	0.44
4	54	40	0.63	0.64
5	66	40	0.61	0.27

Table 2. Dyestuff properties; (VS: Vinyl Sulphone, MCT: Monochlorotriazine).

Dyestuff	Remazol Yellow RR	Remazol Red RR	Remazol Blue RR
Structure	monofunctional	bifunctional	bifunctional
Reactive group	VS	MCT/VS	VS/VS
Reactivity	medium	medium	medium
Substantivity	high	high	medium

Table 3. Dyeing recipes for Remazol RR dyestuffs.

0.5% dye concentration	2% dye concentration	1.5% combination dyeing
0.5% Remazol Yellow/Red/Blue RR 35 g/l Na_2SO_4 7.5 g/l Soda	2% Remazol Yellow/Red/Blue RR 50 g/l Na_2SO_4 13 g/l Soda	0.5% Remazol Yellow RR 0.5% Remazol Red RR 0.5% Remazol Blue RR 45 g/l Na_2SO_4 11.5 g/l Soda

fraction of void space in a porous medium [12]:

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \qquad (2)$$

where ρ_a is the fabric density (g/cm^3) and ρ_b is the fibre density (g/cm^3). Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness. This equation includes the inter-fibre porosity as well as the inter-yarn porosity of the fabric.

This paper presents the effects of warp & weft density of woven fabrics, and in consequence the fabric porosity, on the colour shade and yield in reactive dyeing. This is known practically, although no experimental study on this subject has yet been found .

Experimental

Plain weaved bleached cotton fabrics produced in different warp and weft densities were used for the purpose of investigating the effects of fabric structure and porosity on colour yield. The linear yarn densities of warp and weft yarns were 12 tex (Ne50) and 15 tex (Ne40) respectively. Table 1 represents the characteristics of the fabrics used.

The porosity of the fabrics was calculated by using Equation (2). The mean density of cotton fibres is accepted as 1.52 g/cm^3. The pore area of each fabric was calculated geometrically, considering the plain weave structure with the aid of yarn diameters.

Three different reactive dyes, supplied from the Dystar Company (Remazol Yellow RR, Remazol Red RR and Remazol Blue RR), were used for reactive dyeing. Table 2 represents the properties of the dyestuffs. Dyeing processes were carried out in two different dye concentrations (0.5% and 2%). Furthermore, combination dyeings of these three dyestuffs (0.5% for each one and a total of 1.5%) were also processed.

Reactive dyeing was carried out with a laboratory-scale HT Termal dyeing machine with a liquor ratio of 1:15 according to the 30 °C → 60 °C temperature rise method. The dyeing process was started with a liquor containing alkaline, salt and dyestuff at 30 °C, and after 10 minutes the temperature was raised to 60 °C with a 1 °C/min temperature rise ratio; the samples were then treated for 60 minutes. The dyeing recipe is presented in Table 3. After dyeing, the samples are rinsed and neutralised (10 min. at 60 °C with 0.5 g/l acetic acid), and then rinsed at 80 °C for 10 minutes, 95 °C for 15 minutes (two times for 2% dyeings), 80 °C for 10 minutes, and 5 minutes in cold water.

The reflection (%R) and CIELab values of the samples were measured with a Minolta 3600d spectral photometer with a 10° normal observer and norm light D65.

The colour yields of the dyed samples were calculated by the Kubelka-Munk equation [13]:

$$K/S = (1-R)^2/2R \qquad (3)$$

where R is the reflectance at maximum absorption wavelength (nm), K the absorption coefficient and S the scattering coefficient.

The colour differences are expressed as ΔE, which is calculated by the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \qquad (4)$$

where ΔE^* is the CIELAB colour difference between batch and standard. Here ΔL^*, Δa^*, Δb^* and hence ΔE^*, are in commensurate units. ΔL^* denotes the difference between lightness (where $L^* = 100$) and darkness (where $L^* = 0$), Δa^* the difference between green ($-a^*$) and red ($+a^*$), and Δb^* the difference between yellow ($+b^*$) and blue ($-b^*$).

Results and discussion

Effects of fabric density variation

Tables 4, 5 and 6 represent L^*, a^*, b^* values and ΔL^*, Δa^*, Δb^* and ΔE values (calculated with reference to the sample with weft density of 20 threads/cm) of the reactive dyed fabrics considering weft density variation.

The Δa^* and Δb^* values calculated with reference to the sample with weft density of 20 threads/cm show that the increase in weft density does not have a significant effect on the colour shade of the reactive dyed fabrics both for 0.5% and 2% dye concentrations. However, the increase of weft density has the main effect on the L^* values of the samples. Due to the increase of weft density, the fabrics become denser, and this makes the penetration of the dyestuffs into the fabric more difficult. On this account, fabrics with higher weft density show higher L^* values, i.e. lower colour yields. One thing is especially important for combination dyeing, namely the possibility of colour shade changes if the effects of weft density variation on the uptake properties of the dyestuffs used in trichromy are different.

The colour yields of the samples dyed considering weft density variation are

Table 4. Effects of weft density variation on the CIELab values of reactive dyed fabrics with 0.5% dye concentration (warp density is 60 threads/cm).

Dyestuff	Weft density, threads/cm	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE	K/S
Remazol Yellow RR	20	75.01	18.64	54.00	Std.	Std.	Std.	Std.	2.83
	30	75.55	19.06	54.44	0.54	0.42	0.44	0.81	2.78
	40	76.77	17.85	54.26	1.76	-0.79	0.26	1.95	2.55
Remazol Red RR	20	54.16	45.98	-3.40	Std.	Std.	Std.	Std.	3.81
	30	54.28	46.18	-3.56	0.12	0.21	-0.06	0.25	3.79
	40	55.80	46.83	-3.71	1.64	0.85	-0.18	1.86	3.50
Remazol Blue RR	20	48.55	-9.74	-16.45	Std.	Std.	Std.	Std.	3.84
	30	48.67	-9.79	-16.52	0.12	-0.05	-0.08	0.15	3.81
	40	51.45	-10.16	-16.84	2.90	-0.42	-0.40	2.95	3.20

Table 5. Effects of weft density variation on the CIELab values of reactive dyed fabrics with 2% dye concentration (warp density is 60 threads/cm).

Dyestuff	Weft density, threads/cm	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE	K/S
Remazol Yellow RR	20	68.01	29.39	68.16	Std.	Std.	Std.	Std.	8.37
	30	68.26	30.30	68.42	0.25	0.91	0.26	0.98	8.31
	40	69.56	29.34	68.96	1.54	-0.05	0.80	1.74	7.71
Remazol Red RR	20	41.48	53.51	2.13	Std.	Std.	Std.	Std.	12.87
	30	41.94	53.43	2.15	0.45	-0.08	0.01	0.46	12.27
	40	43.39	53.79	1.41	1.90	0.28	-0.72	2.05	10.84
Remazol Blue RR	20	31.42	-7.74	-17.29	Std.	Std.	Std.	Std.	13.10
	30	31.82	-7.65	-17.70	0.40	0.09	-0.41	0.58	12.73
	40	33.21	-8.04	-18.12	1.80	-0.30	-0.83	2.00	11.61

Table 6. Effects of weft density variation on the CIELab values of combination dyed fabrics with 1.5% total dye concentration (warp density is 60 threads/cm).

Weft density, threads/cm	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE	K/S
20	37.15	8.40	-1.23	Std.	Std.	Std.	Std.	5.04
30	38.49	7.78	-1.57	1.34	-0.62	-0.35	1.52	4.55
40	38.93	7.89	-1.80	1.78	-0.51	-0.58	1.94	4.41

shown in Figure 1. By increasing weft density, the colour yields of the samples decrease. The relation between fabric density and colour yield was investigated by correlation analysis with the significance value (α) of 0.05. The results showed that the colour yield change by weft density variation is statistically significant for all shades. On the other hand, the effect of warp yarn density variation is statistically insignificant. The lowest colour yield change occurred in the samples dyed with Remazol Yellow RR. This is because the *L** value of the yellow colour is the highest (i.e. the lightest and brightest), and the increased dyestuff concentration leads to an insignificant change in the yellow colour when compared to the red or blue colours. Another important point is that the colour yield change is more significant in dyed samples with 2% dye concentration. In 0.5% dyeing, the dye liquor contains a lower amount of dyestuffs, thus there are no excess dyestuffs which the loose fabrics could take up. On the other hand, by increasing the dye concentration, loose fabrics can take up more dyestuffs compared to dense fabrics.

It was observed that warp yarn density variation does not have a significant effect on the colour shade for both 0.5% and 2% dye concentration. Also, there is no significant colour yield difference between the fabrics. This is probably because of the lower difference between the warp yarn densities of the samples used in this study (fabrics with warp density of 60 and 66 threads/cm are respectively 11.11% and 22.22% denser than the sample with a warp density of 54 threads/cm) compared to weft density variation (fabrics with a weft density of 30 and 40 threads/cm are 50% and 100% denser respectively than the sample with a weft density of 20 threads/cm). However, a significant variation in warp density would cause a much greater difference in the dye uptake properties of the fabrics, which leads to an important colour difference.

Effects of porosity and pore dimensions on colour yield

As shown in Figure 2, the higher the porosity of the fabrics, the higher the colour

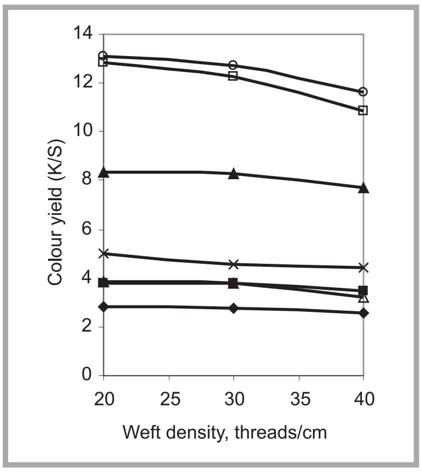

Figure 1. Effects of weft density variation on colour yield (K/S); ♦ - 0.5 Yellow, ■ – 0.5 Red, Δ - Blue, ▲ – 2% Yellow, □ – 2% Red, ○ – 2% Blue, × - 1.5 Combination.

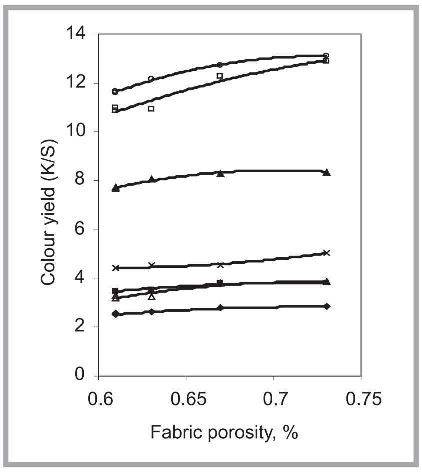

Figure 2. Effects of porosity on colour yield (K/S); ♦ - 0.5 Yellow, ■ – 0.5 Red, Δ - Blue, ▲ – 2% Yellow, □ – 2% Red, ○ – 2% Blue, × - 1.5 Combination.

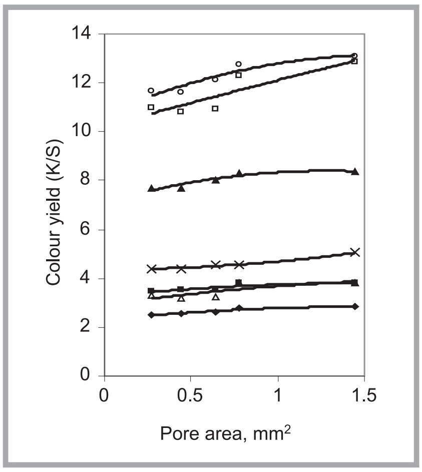

Figure 3. Effects of pore dimensions on the colour yield (K/S); ♦ - 0.5 Yellow, ■ – 0.5 Red, Δ - Blue, ▲ – 2% Yellow, □ – 2% Red, ○ – 2% Blue, × - 1.5 Combination.

yields. This increase is more significant in dark shades. For dense fabrics, the resistance to liquor flow is higher than loose fabrics, and thus the liquor penetration into the fabric is more difficult.

Pore area can also be taken as a factor that affects colour yield, as well as porosity, because fabrics with the same porosity can have different pore dimensions. For instance, considering two fabrics with the same porosity, fabrics produced with fine yarns have larger pores when compared to fabrics produced with coarse yarns. Figure 3 (see page 91) represents the effects of pore dimensions on the colour yields of the dyed fabrics. This increase is more significant in dark shade dyeings, as mentioned above. In this study, the effects of porosity and pore area on colour yield are analogous because there is no difference between the yarn linear densities. It was observed that the effects of porosity and pore dimensions of the samples on the L^* values of the dyed fabrics are stronger than the effects on a^* and b^* values. A correlation analysis was carried out (α=0.05) in order to investigate the effects of porosity and pore dimensions on colour yield. It was observed that colour yield change due to porosity and pore dimension variation is statistically significant.

Conclusion

One of the important points in dyeing is that of the acceptable colour difference limits. In fact, there is no certain value for a colour difference (ΔE) acceptance limit. Practically, this value is 1-2 depending on the agreements between the consumer and the manufacturer. Fabric structure difference is always a problem for the mills, where colour matching is done on the basis of colouristic experience. On this account, the effects of physical parameters of the fabrics such as weave sett, porosity, etc. on the colour effects should be established.

In this research, we have focused on the effects of the fabric structure on the problem of colour matching. Warp & weft yarn density variation do not affect the colour shades independent of dye concentration. However, the L^* values of the samples increase by increasing warp & weft yarn density. When the warp & weft densities are increased, the colours of the dyed fabrics become lighter. In parallel with L^*, the colour yield (K/S) of the fabrics decreases by increasing fabric tightness, especially for dark shade dyeing. Furthermore, tight fabrics have lower porosity where the resistance to dye liquor penetration is difficult. This means that porosity can be taken as a factor for the colour matching. In the view of these observations, it is obvious that fabric tightness and porosity directly affect the colour yield, and should be taken into account when considering the problems of colour reproducibility.

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