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Sulphur dyes on nylon 6,6—part 1: the effects of temperature and pH on dyeing

S.M. Burkinshaw[a,*], K. Lagonika[a], D.J. Marfell[b]

[a]School of Textiles and Design, The University, Leeds, LS2 9JT, UK
[b]Du Pont Nylon (UK), Brockworth, Gloucester, GL3 4HP, UK

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Abstract

Nylon 6.6 was dyed with five commercial sulphur dyes at different pH values and various temperatures. It was found that over the pH range 6–12, maximum colour strength was achieved at pH 7 and the colour of the dyeings was influenced by the pH at which dyeing had been carried out. The latter observation was explained in terms of the effect of pH on the state of reduction of the dyes and their subsequent oxidative condensation. The five dyes varied in terms of the effect of dyeing temperature, over the range 50–120 °C, on colour strength. Generally, within the range 70–98 °C, temperature had little effect on the colour of the dyeings whereas both lower dyeing temperatures (50 and 60 °C) and, especially, higher temperatures (110 and 120 °C) resulted in colour change. In terms of wash fastness, dyeing temperature had little influence on shade change or staining of adjacent multifibre material. With the exception of the black dye used, the dyeings displayed poor fastness to light; dyeing temperature had little effect on light fastness.

Keywords: Nylon 6,6; Sulphur dyes; Repeated wash fastness; Light fastness

1. Introduction

Nylon 6,6 can be dyed using several classes of dye (*acid*,*mordant, direct, reactive, disperse*, *vat* and *basic*) and a considerable body of literature has been published on the use of these dye classes on nylon 6,6 since the fibre's commercial introduction over 60 years ago. In contrast, remarkably few references have appeared that concern the application of sulphur dyes to nylon 6,6. A preliminary study by two of the present authors [1] showed that nylon 6,6 could be dyed with selected sulphur dyes using either a sulfide-based reduction system intended for the application of the dyes to cellulosic fibres or a glucose/NaOH reduction system. The ensuing dyeings displayed good fastness to repeated wash testing and very good resistance to oxygen bleach fading. While the sulphur dyeings on nylon 6,6 showed excellent wet and rub fastness, the light fastness of the dyeings was poor.

Research work undertaken during the initial study [1] stimulated commercial interest in the dyeing of nylon 6,6 with sulphur dyes, which, in turn, led to the need to understand more fully, the effects of application parameters (pH, temperature,

* Corresponding author. Tel.: +44-113-233-3722; fax: +44-113-233-3740.
E-mail address: s.m.burkinshaw@leeds.ac.uk (S.M. Burkinshaw).

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liquor ratio, etc.) on dyeing as well as the mechanism of dyeing. This particular part of the paper concerns the effects of temperature and pH of application on the colour strength, fastness to light and to repeated washing of five sulphur dyes on nylon 6,6. Further parts of the paper will consider the effects of other application parameters (reductant, oxidant and liquor ratio) on dyeing and fastness while the final part of the paper will deal with the mechanism of dyeing nylon 6,6 with sulphur dyes.

2. Experimental

2.1. Fabric

Knitted, nylon 6,6 *Coloursafe* fabric (78f68) fabric, supplied by Du Pont Nylon (UK), was scoured in a solution comprising 2 g l^{-1} $Na_2\,CO_3$ and 5 g l^{-1} of the non-ionic surfactant *Sandozin NIE* (Clariant) for 20 min at 70 °C. The scoured fabric was rinsed thoroughly in tap water and allowed to dry in the open air.

2.2. Dyeing

Commercial samples of five, arbitarily chosen, sulphur dyes were used (Table 1); the dyes were provided by Clariant UK and were used without purification. Dyeings (10% omf) were carried out in 300 cm^3 capacity sealed stainless steel dyepots, housed in a *Roaches Pyrotec S* dyeing machine at 50, 60, 70, 80, 90, 98, 110 and 120 °C using a 20:1 liquor ratio (Fig. 1). Dyeing was undertaken at pH 6–12; Mcllvaine buffer [2] was used to achieve pH values in the range 3–8 (Table 2), while for pH values higher than 8, an aqueous solution comprising 5 g dm^{-3} of Na_2HPO_4 and 1 g dm^{-3} of potassium orthophosphate solution was used, to which was added an appropriate amount of an aqueous 4 g dm^{-3} NaOH solution, to achieve the desired pH. A commercial reducing agent, *Formosul GR* (Clariant) was used. At the end of dyeing, the dyed sample was removed, rinsed thoroughly in tap water and were oxidised.

2.3. Oxidation

Dyeings were oxidised using 5 g l^{-1} *Diresul BRI* (Clariant UK) at pH 4.5 (McIlvaine buffer; Table 2) using a liquor ratio of 50:1, at 60 °C, for 15 min in 300 cm^3 capacity sealed stainless steel dyepots, housed in a *Roaches Pyrotec S* dyeing machine. At the end of oxidation, the samples

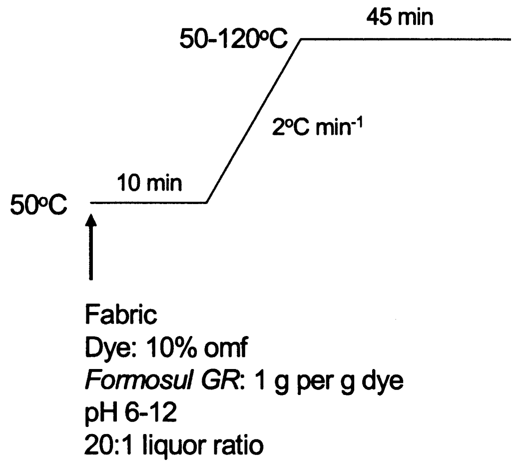

Fig. 1. Dyeing method.

Table 1
Dyes used

Commercial name	C.I Generic name
Diresul Green RDT-N	Sulphur Green 2
Diresul Yellow RDT-E	Sulphur Yellow 22
Diresul Brown RDT-GN	Sulphur Brown 1:1
Diresul Navy 2R	Sulphur Navy 11
Diresul Black RDT-LS200%	Sulphur Black 1

Table 2
Composition of McIlvaine buffer [2]

pH	0.2 M Na_2HPO_4 (cm^3)	0.1 M Citric acid (cm^3)
3	20.6	79.4
4	38.6	61.4
4.5	42.3	52.3
5	51.5	48.5
6	63.2	36.8
7	82.4	17.6
8	97.3	2.7

were rinsed in running cold water for 5 min and allowed to dry in the open air.

2.4. Wash-fastness

The dyed fabric was subjected to five, consecutive ISO CO6/C2 [3] wash tests; at the end of each wash test, the washed sample was rinsed thoroughly in tap water but was not dried. A fresh sample of SDC multifibre strip was used to assess the extent of staining for each of the five wash tests.

2.5. Light fastness

The fastness of the dyeings to light was determined using the ISO B02 method [3].

2.6. Colour measurement

All measurements were carried out using an *X-rite* spectrophotometer interfaced to a PC using D_{65} illumination, 10° standard observer with specular component excluded and UV component included. Each fabric was folded once to give two thickness and an average of four readings was taken each time.

3. Results and discussion

3.1. Effect of dyeing pH

In this initial part of the study, the five dyes were applied (Fig. 1) at 98 °C using *Formosul GR* as reducing agent at pH values between 6 and 12 and the ensuing dyeings were oxidised. Fig. 2 shows the colour strength (f_k) obtained for the 10% omf dyeings as a function of application pH, from which it is evident that, in general, maximum colour strength was achieved at pH 7 and thereafter decreased with further increase in pH. The corresponding colorimteric data (Table 3) reveals that the pH at which dyeing had been carried out not only affected the colour strength of the dyeings but also influenced the colour of the dyeings; in the latter context, application at pH 6 and pH 12 had greatest influence on colour. The observed dependency of the colour of the dyeings on the pH at which dyeing was carried out can be explained in terms of the effect of pH on the state of reduction of the dyes and their subsequent oxidative condensation.

Although sulphur dyes have been widely used for many decades, primarily on cellulosic fibres, little is known about their chemical structure and

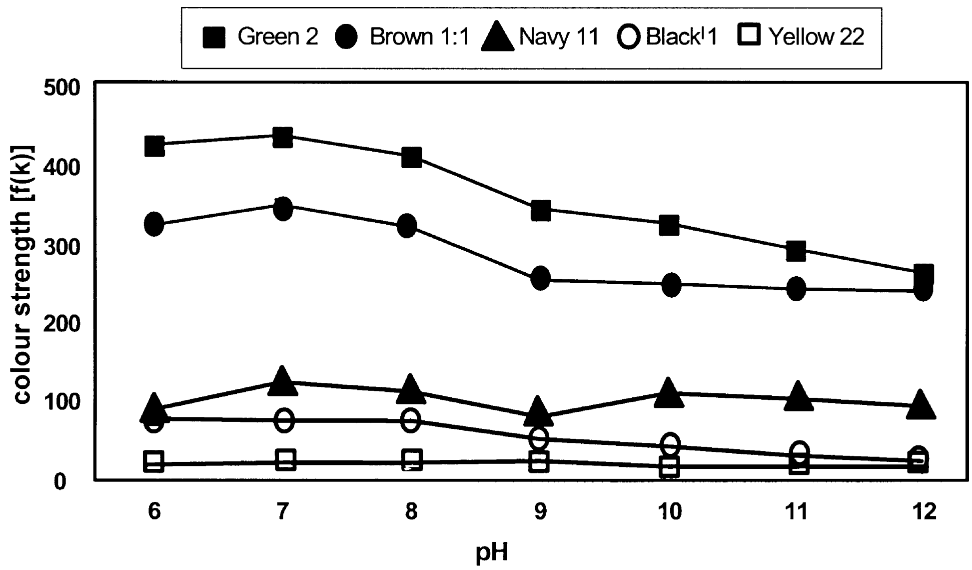

Fig. 2. Colour strength as a function of application pH at 98 °C.

Table 3
Effect of application pH on colorimetric data at 98 °C

Dye	pH	Washes	*L**	*a**	*b**	C	h°	λ_{max}
Green 2	6	0	40.6	−7.4	4.6	8.7	148.1	400
		5	41.2	−7.4	4.5	8.5	148.0	400
	7	0	33.4	−16.5	−10.4	19.5	212.1	660
		5	37.1	−20.3	−9.3	22.3	204.7	640
	8	0	35.2	−18.2	−8.7	20.1	205.6	640
		5	35.1	−18.0	−10.4	20.7	210.0	640
	9	0	42.0	−25.0	−7.5	26.1	196.7	660
		5	43.6	−24.8	−7.5	26.1	197.5	660
	10	0	35.9	−18.9	−9.6	21.2	206.8	640
		5	37.1	−20.7	−9.3	22.6	204.1	640
	11	0	38.2	−20.1	−10.1	22.2	206.7	640
		5	42.8	−24.8	−7.8	26.0	197.4	640
	12	0	42.8	−24.8	−7.6	22.8	206.4	640
		5	42.9	−24.9	−7.4	22.5	206.7	640
Brown 1:1	6	0	37.8	3.5	10.6	17.2	72.0	400
		5	40.1	3.3	10.5	17.2	72.4	400
	7	0	38.6	3.8	12.7	17.3	72.8	400
		5	39.4	3.9	12.8	17.2	72.4	400
	8	0	41.6	4.7	15.5	16.2	73.2	400
		5	46.7	2.8	16.0	16.3	80.0	400
	9	0	47.7	3.1	16.1	16.4	79.3	400
		5	49.6	3.1	16.0	16.0	79.7	400
	10	0	50.7	4.7	16.6	17.2	74.2	400
		5	54.3	3.9	17.5	17.9	77.5	400
	11	0	57.2	7.1	19.9	21.2	70.3	400
		5	61.5	6.4	20.9	21.8	73.0	400
	12	0	63.0	6.5	21.8	20.9	71.1	400
		5	63.2	6.4	21.5	20.1	71.0	400
Navy 11	6	0	16.8	7.2	−19.2	20.5	290.5	600
		5	17.0	7.2	−19.4	19.7	287.5	600
	7	0	16.1	7.7	−19.9	21.3	291.3	600
		5	19.2	7.6	−21.9	23.2	289.0	600
	8	0	17.1	6.8	−19.6	20.8	289.1	600
		5	17.8	7.3	−20.7	22.0	289.4	600
	9	0	19.8	9.8	−24.1	26.1	292.1	600
		5	18.8	9.4	−25.0	26.0	291.8	620
	10	0	18.7	8.0	−21.5	23.0	290.5	600
		5	18.2	8.0	−21.4	22.5	282.1	600
	11	0	19.0	8.4	−22.9	22.1	287.1	600
		5	18.6	8.5	−22.6	24.2	290.6	600
	12	0	19.1	8.4	−22.7	21.5	267.5	600
		5	19.4	8.0	−22.3	21.1	261.5	600
Yellow 22	6	0	77.4	−1.5	40.9	41.0	92.2	400
		5	77.2	−1.5	40.9	40.9	92.3	400
	7	0	76.1	−1.5	42.0	42.1	92.0	400
		5	76.7	0.1	48.4	48.4	89.9	400
	8	0	77.3	0.0	44.6	44.6	90.1	420
		5	82.4	−2.2	41.3	41.4	93.0	400
	9	0	77.0	−4.7	46.3	46.5	95.8	420
		5	77.2	−4.6	46.1	46.5	95.3	420
	10	0	80.8	−2.3	45.1	45.2	92.9	400

(*continued on next page*)

Table 3 (*continued*)

Dye	pH	Washes	L^*	a^*	b^*	C	h°	λ_{max}
		5	80.3	−2.0	47.0	45.2	92.5	400
	11	0	78.9	−2.0	47.2	47.3	92.2	400
		5	78.1	−2.0	47.1	47.1	91.2	400
	12	0	77.4	−4.5	46.0	47.0	91.1	400
		5	77.2	−4.4	46.0	46.3	91.0	400
Black 1	6	0	14.5	−0.6	−1.7	1.0	242.5	620
		5	15.3	−0.5	−1.5	1.1	240.3	620
	7	0	15.0	−0.6	−1.6	1.7	250.4	620
		5	15.2	−0.2	−1.7	1.7	262.4	600
	8	0	15.6	−0.4	−1.5	1.5	256.3	620
		5	17.5	−0.4	−1.4	1.5	249.4	620
	9	0	17.5	−0.7	−1.4	2.1	244.3	620
		5	17.7	−0.5	−1.5	2.1	235.7	620
	10	0	15.6	−0.4	−1.5	1.5	256.3	600
		5	19.4	−0.3	−1.8	2.7	261.4	600
	11	0	19.0	−0.3	−1.4	2.4	263.0	600
		5	19.7	−0.3	−1.8	2.8	264.8	600
	12	0	19.7	−0.3	−1.9	1.5	269.1	640
		5	19.2	−0.2	−1.9	1.4	250.1	640

the mechanism of dyeing. Sulphur dyes are water-insoluble macromolecules that comprise di- and polysulfide linkages between aromatic residues. Cotton (and other cellulosic fibres) is dyed with sulphur dyes, traditionally under alkaline, reducing conditions, the ensuing reduced (leuco) form of the dye being alkali soluble; the oxidised form, which is finally produced within the fibre, is insoluble. Reduction of the dye affects the constituent di- and polysulfide bonds in the dye and results in cleavage of the large M_r dyes, with the formation of the low M_r, alkali-soluble, thiol form of the dye. Oxidation, at the end of dyeing, of the leuco form of the dye is, in essence, oxidative condensation, in which a macromolecular dye is formed in situ within the fibre. From the foregoing, it follows that the final colour achieved in the sulphur dyeing of cotton will depend upon the nature of the reduced species present in the dyebath (i.e. the state of reduction of the dye) and their subsequent oxidative condensation (i.e. the nature of the oxidation process).

If it is assumed that similar reduction and oxidation mechanisms apply to the dyeing of nylon 6,6 with sulphur dyes, then in terms of the observed dependency of the colour of the dyeings on dyeing pH (Table 3), it seems reasonable to suggest that pH would effect dye reduction in terms of the solubility, M_r and relative amounts of the alkali-soluble thiols generated. Subsequent oxidation can also be considered to contribute to the colour of the final dyeings in terms of the solubility, M_r and relative amounts of dye macromolecules that were generated. It can be proposed that the colour of the dyeings was more influenced by the effect of pH on the nature of the reduced species present in the dyebath rather than the oxidation stage, as only one oxidation process was used in this particular part of the work.

In terms of wash fastness, Table 4 shows that the dyeings displayed very good fastness to the five repeated wash tests in terms of shade change; from the viewpoint of staining of adjacent multifibre strip, Table 5 reveals that very little staining occurred. If it is assumed that similar reduction and oxidation mechanisms apply to the dyeing of nylon 6,6 with sulphur dyes as to the dyeing of cellulosic fibres, then the generally high fastness achieved for the dyeings to repeated washing can be attributed to the insolubility of the oxidised dyes. Table 6 reveals that with the exception of the black dye, the dyeings displayed poor fastness to light; it is evident that for all five dyes used, highest light fastness was secured when dyeing had

Table 4
Effect of application pH on shade change achieved for 10% omf dyeings at 98 °C

pH	Green 2 (no. of washes)					Brown 1:1 (no. of washes)					Navy 11 (no. of washes)					Yellow 22 (no. of washes)					Black 1 (no. of washes)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6	4	5	5	5	5	3	3	3	4	4	3	3	4	4	4	3	3	4	4	4	4	5	5	5	5
7	4	5	5	5	5	3	4	4	4	4	3	4	4	4	4	3	4	4	4	4	3	4	4	5	5
8	4/5	5	5	5	5	3/4	4	4	5	5	4	4	5	5	5	4	4	5	5	5	4/5	5	5	5	5
9	5	5	5	5	5	4	5	5	5	5	4/5	5	5	5	5	4	4	5	5	5	4/5	5	5	5	5
10	5	5	5	5	5	4/5	5	5	5	5	4/5	5	5	5	5	4/5	5	5	5	5	4	5	5	5	5
11	4	5	5	5	5	5	5	5	5	5	4/5	5	5	5	5	5	5	5	5	5	4	5	5	5	5
12	4	4/5	5	5	5	4	5	5	5	5	4	4	5	5	5	4	4/5	5	5	5	4	4/5	5	5	5

Table 5
Effect of application pH on staining of adjacent multifibre achieved for 10% omf dyeings at 98 °C

No. of washes	Staining of[a]	
	Cotton	Nylon 6,6
Green 2		
1	4/5	5
2	4/5	5
3	5	5
4	5	5
5	5	5
Brown 1:1		
1	3/4	4
2	4	4/5
3	4/5	5
4	5	5
5	5	5
Navy 11		
1	3/4	4
2	3/4	4
3	3/4	4/5
4	4	5
5	4	5
Yellow 22		
1	3/4	4
2	3/4	4
3	4	5
4	4	5
5	4	5
Black 1		
1	4	5
2	4/5	5
3	5	5
4	5	5
5	5	5

[a] No staining of the acetate, acrylic, polyester or wool components of the multifibre strip was obtained.

Table 6
Effect of application pH on light fastness of 10% omf dyeings at 98 °C

pH	Green 2	Brown 1:1	Navy 11	Yellow 22	Black 1
6	2	2	2	2	5
7	2/3	2/3	2/3	2/3	6
8	2	2	2	2	6
9	3	2	2	2	4
10	2	2	2	2	5
11	2	2	2	2	4
12	2	2	2	2	4

been carried out at pH 7. These findings were not surprising in view of the findings made in a preliminary study of the dyeing of nylon 6,6 with sulphur dyes by two of the present authors [1]. The exceptionally high light fastness obtained for the black dye was anticipated as this particular dye, namely C.I. Sulphur Black 1, famously exhibits very good light fastness on cellulosic fibres even in pale depths [4].

3.2. Effect of dyeing temperature

Consequent upon the findings described above that dyeing at pH 7 imparted highest colour strength and light fastness to the dyeings, in this part of the study, the five dyes were applied (Fig. 1) at pH 7 at 50, 60, 70, 80, 90, 98, 110 and 120 °C. Fig. 3 shows that the dyes varied in terms of the effect of dyeing temperature on colour strength. For the black dye, the f(k) of the dyeings increased

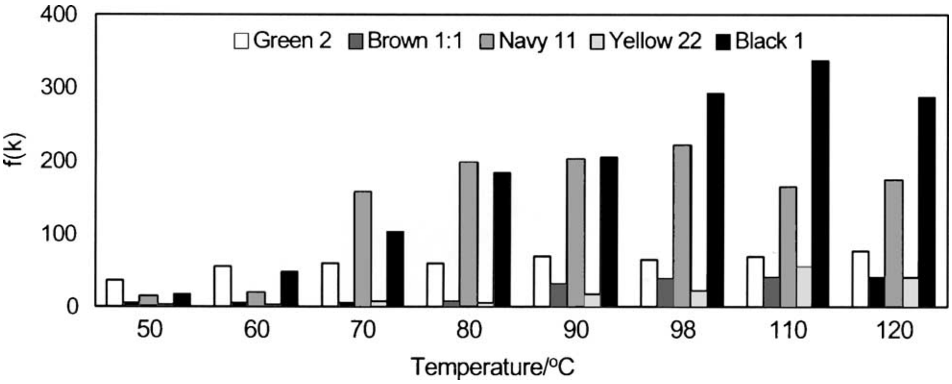

Fig. 3. Effect of application temperature on colour strength achieved at pH 7.

Table 7
Effect of application temperature on colorimetric data for 10% omf dyeings at pH 7

	Temp/°C	*L**	*a**	*b**	C	h	λ_{max}
Green 2	50	51.2	−19.2	−10.0	21.6	207.6	640
	60	44.7	−18.3	−10.5	21.1	209.8	640
	70	43.8	−18.0	−10.0	20.6	209.0	640
	80	43.8	−18.2	−9.5	20.5	207.6	640
	90	41.9	−18.6	−10.4	21.3	209.2	640
	98	42.8	−18.7	−9.5	21.0	207.0	640
	110	40.2	−18.3	−10.2	20.9	209.2	640
	120	40.2	−18.2	−10.0	20.6	207.6	640
Brown 1:1	50	78.1	0.9	5.2	5.3	80.3	400
	60	77.4	1.0	6.4	6.5	80.8	400
	70	76.5	1.5	8.1	8.2	79.2	400
	80	71.8	1.8	9.7	9.9	79.7	400
	90	52.7	1.8	9.4	9.6	79.5	400
	98	49.6	1.0	9.9	9.9	84.3	400
	110	50.1	2.9	13.2	13.5	77.4	400
	120	58.1	2.9	13.2	14.3	80.3	400
Navy 11	50	41.1	−0.7	−15.7	15.7	267.4	600
	60	38.1	0.6	−16.9	16.9	272.0	600
	70	36.2	1.2	−16.6	16.6	274.0	600
	80	33.0	0.9	−16.0	16.0	273.4	600
	90	31.3	0.8	−15.3	15.4	273.0	600
	98	34.0	1.1	−15.4	15.4	274.2	600
	110	34.0	0.3	−13.1	13.1	271.2	600
	120	37.0	−0.3	−13.7	13.7	267.4	600
Yellow 22	50	84.5	6.2	5.4	8.2	41.4	400
	60	80.6	7.0	3.9	8.1	29.2	400
	70	73.4	15.4	5.5	16.3	19.6	400
	80	76.5	13.1	4.8	13.9	20.1	400
	90	67.0	23.7	6.1	24.5	14.4	400
	98	47.6	35.7	15.0	38.7	22.7	400
	110	65.9	26.1	5.6	33.4	13.5	400
	120	84.5	6.2	5.4	8.2	41.4	400
Black 1	50	57.5	−0.6	−1.7	1.8	251.0	400
	60	43.4	−1.0	−2.8	3.0	249.8	620
	70	33.6	−0.9	−2.7	2.9	252.0	620
	80	26.9	−0.4	−2.9	3.0	263.1	600
	90	21.6	−0.7	−2.8	2.9	255.2	600
	98	18.2	−0.7	−2.0	2.1	252.1	620
	110	15.8	−0.4	−1.8	1.8	258.6	620
	120	15.7	−0.4	−1.8	1.8	251.0	400

Table 8
Effect of application temperature on shade change achieved for 10% omf dyeings at pH 7

Temp./ °C	Green 2 (no. of washes)					Brown 1:1 (no. of washes)					Navy 11 (no. of washes)					Yellow 22 (no. of washes)					Black 1 (no. of washes)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
60	4/5	5	5	5	5	3/4	4	4	5	5	3/4	4	5	5	5	4	4	5	5	5	4/5	5	5	5	5
70	4	5	5	5	5	3/4	4	4	5	5	3/4	4	4	5	5	3/4	4	5	5	5	4	5	5	5	5
80	4/5	5	5	5	5	4	5	5	5	5	3	3/4	4	4	4	3/4	4	4	5	5	4	4/5	5	5	5
90	5	5	5	5	5	3/4	4	4	5	5	4	4	5	5	5	3/4	4	4	4	5	4/5	5	5	5	5
98	5	5	5	5	5	4	4	5	5	5	4	4	5	5	5	4/5	4	4	4	4	4	4/5	5	5	5
110	4	4	5	5	5	3/4	4	4	4	4/5	4	4/5	5	5	5	4	4	5	5	5	4/5	5	5	5	5
120	4	4	5	5	5	3/4	4	5	5	5	3/4	4	4	5	5	4	4	5	5	5	4/5	5	5	5	5

Table 9
Effect of application temperature on staining[a] of adjacent multifibre achieved for 10% omf dyeings at pH 7

Dye	Temp/°C	No. of washes									
		1		2		3		4		5	
		Cotton	Nylon 6,6	Cotton	Nylon 6,6	Cotton	Nylon 6,6	Cotton	Nylon 6,6	Cotton	Nylon 6,6
Green 2	60	4	5	4/5	5	5	5	5	5	5	5
	70	4	5	4/5	5	5	5	5	5	5	5
	80	4	5	4/5	5	5	5	5	5	5	5
	90	4	4	4	4/5	5	5	5	5	5	5
	98	4	5	4/5	5	5	5	5	5	5	5
	110	5	5	5	5	5	5	5	5	5	5
	120	5	5	5	5	5	5	5	5	5	5
Brown 1:1	60	3/4	4	4	4/5	4/5	5	5	5	5	5
	70	3	4	4	4	4	5	4	5	4	5
	80	4	4	4	4	4	5	4	5	4	5
	90	3/4	4/5	3/4	4/5	5	4	5	5	5	5
	98	3/4	5	4	5	4	5	4	5	4	5
	110	4	5	4	5	4	5	4	5	4	5
	120	4	5	4	5	5	5	5	5	5	5
Navy 11	60	3/4	4	3/4	4	3/4	4/5	4	5	4	5
	70	3/4	5	4	5	4	5	5	5	5	5
	80	3	4/5	4	5	4	5	5	5	5	5
	90	3	4	3/4	4/5	3/4	5	4	5	4	5
	98	3/4	4	4/5	4	5	4/5	5	5	5	5
	110	4	5	4	5	4	5	4/5	5	4/5	5
	120	4	5	4	5	4	5	4/5	5	4/5	5
Yellow 22	60	3/4	4	3/4	4	4	5	4	5	4	5
	70	4	4	4	4	4	5	4	5	4	5
	80	4	4	4	4	4	5	4	5	4	5
	90	3/4	4	3/4	4	5	5	5	5	5	5
	98	3/4	4	3/4	4	4	5	4	5	4	5
	110	4	4	4	5	4	5	4	5	4	5
	120	4	4	4	5	4	5	4	5	4	5
Black 1	60	4	5	4/5	5	5	5	5	5	5	5
	70	4	5	4/5	5	5	5	5	5	5	5
	80	3/4	4/5	3/4	5	4	5	5	5	5	5
	90	3/4	4	3/4	4/5	3/4	5	4	5	4	5
	98	4	5	4/5	5	5	5	5	5	5	5
	110	4	5	4	5	4	5	4/5	5	4/5	5
	120	4	5	4	5	4	5	4/5	5	4/5	5

[a] No staining of the acetate, acrylic, polyester or wool components of the multifibre strip was obtained.

Table 10
Effect of application temperature on light fastness of 10% omf dyeings at 98 °C

Temp/°C	Green 2	Brown 1:1	Navy 11	Yellow 22	Black 1
60	3	3	3	3	6
70	2/3	2/3	3	3	5/6
80	2	2	2	2/3	6
90	2	2	2	2/3	6
98	2	2	2	2	6
110	2	2	2/3	2	6
120	2	2	2	2	6

markedly with increasing application temperature, from 60 °C, reaching maximum colour strength at 110 °C. Similar behaviour was obtained for the navy dye, in that colour strength increased markedly with increasing temperature from 70 °C but maximum f(k) was achieved at 98 °C. In contrast, the depth of shade achieved for the green, brown and yellow dyes only very gradually increased with increasing temperature over the range studied. Table 7 reveals that, generally, within the range 70–98 °C, temperature had little effect on the colour of the dyeings. However, lower dyeing temperatures (50 and 60 °C) and especially higher temperatures (110 and 120 °C) caused resulted in colour change. In terms of wash fastness, dyeing temperature had little influence on shade change (Table 8) or staining of adjacent multifibre material (Table 9). Table 10 reveals that with the exception of the black dye used, the dyeings displayed poor fastness to light; it is evident that for all five dyes used, dyeing temperature had little effect on light fastness.

4. Conclusions

For the five dyes used, maximum colour strength was achieved at pH 7 and the colour of the dyeings was influenced on the pH at which dyeing had been carried out. The latter observation can be attributed to the effect of pH on the state of reduction of the dyes and their subsequent oxidative condensation. The five dyes varied in terms of the effect of dyeing temperature on colour strength. For two of the dyes, f(k) increased markedly with increasing application temperature and reached a maximum at 98–110 °C whereas the depth of shade achieved for the remaining three dyes only very gradually increased with increasing temperature from 50 to 120 °C. Generally, temperature had little effect on colour of the dyeings within the range 70–98 °C whilst both lower temperatures (50 and 60 °C) and, especially, higher temperatures (110 and 120 °C) imparted marked colour change. Dyeing temperature had little effect on the fastness of dyeings to light and repeated washing. With the exception of the black dye used, the dyeings displayed poor fastness to light.

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