ELSEVIER

0143-7208(94)00032-8

Dyes and Pigments **26** (1994) 237–246

0143-7208/94/$7.00

Simulation of Unlevelness in Loose Stock Dyeing

S. H. Amirshahi & M. T. Pailthorpe*

Department of Textile Technology, School of Fibre Science and Technology, University of New South Wales, Sydney, New South Wales 2052, Australia

(Received 10 June 1994; accepted 6 July 1994)

ABSTRACT

A simulation model has been developed for the analysis of unlevelness in loose stock. The proposed model has shown that two quite different problems can arise from this kind of unlevelness, viz. mismatching and colour broken effects. For pale shades, acceptable colour tolerances and solid colours are achievable, even for unlevel dyeings, after later blending processes. On the other hand, for dark shades, elimination of the unlevelness is not as easy because of the effect of both colour tolerance and colour broken effects.

1 INTRODUCTION

Loose stock dyeing is a common dyeing method, especially in the woollen and worsted industry. Loose stock is dyed in a package dyeing machine; however the machine is usually more heavily loaded than for yarn or hank dyeing. In order to prevent channelling in the dyeing basket, it is necessary to uniformly pack the fibre using mechanical pressure in the wet condition.

Dyers can be less careful when they dye in this form, because they may believe that the levelness and/or colour-tolerance requirements are less critical for this form of dyeing. This is so because unlevelness, and other variations, are eliminated in the later blending steps.[1,2]

In addition, the amounts of auxiliaries and chemicals which are normally added to the bath are reduced to a minimum in stock dyeing. Furthermore, the rate of rise of temperature can be more rapid, and hence

* To whom correspondence should be addressed.

exhaustion is achieved more quickly. All of these factors play a great economic role and, in combination, make the dyeing process faster and cheaper.

Thus one should put the question 'Is it always possible to eliminate unlevel dyeing results in the later blending processes or not?' An answer to this question would help us to determine the possible degrees of freedom in loose stock dyeing and hence optimise the dyeing conditions.

Before categorising unlevelness, it is necessary to define exactly what is 'an unlevel dyeing'. According to Welham,[3] a dyeing is said to be unlevel when the material does not exhibit the same depth of shade over the whole of its area. Unlevelness in loose stock dyeing can be categorised as:

(1) Insufficient penetration of dyestuff into the more compact areas of the fibre basket (especially in an overloaded vessel).
(2) Incompatibility of the dyes which have been selected to match a specific shade.
(3) (1) and (2) simultaneously.

If one assumes that there have been no errors in dye selection, then one only has to consider the first case.

In loose stock dyeing, liquor circulation is normally from the inside to the outside, without any interruption. In addition, those fibres which plasticise easily are compressed by the pressure of the liquid, so that the rate of circulation is reduced during the dyeing process.[4]

On the other hand, the dyeability of the fibres plays an important role in the dyeing results. For example, fibres with a limited number of dye sites, such as acrylic fibres, cause more difficulties than other fibre types which have different dye absorption properties. All of these parameters can have an effect on the dyeing result and may lead to insufficient penetration of the dyes into the compacted areas of the dyeing vessel.

Normally, the result of an unlevel dyeing batch is a series of coloured fibres with different dyeing depths. In contrast with the level dyed condition, the dyeing depth of non-compacted areas should be heavier, and the dyeing depth would decrease as one moves closer to the compacted areas. In the most extreme case, it is possible to find undyed fibres in the more compacted areas of the dyeing vessel. Thus we must assume that, in such extreme conditions, one is faced with only two groups of fibres, namely dyed and undyed fibres. So in this case, there is a similarity between the blending of unlevel loose stock dyed production and the deliberate blending of pre-coloured fibres.

Two different problems can arise with unlevel stock dyeing:

(i) colour mismatching, and
(ii) the creation of colour broken effects.

In this work a white, a black and a series of grey pre-coloured fibres have been used to simulate unlevel loose stock dyeing.

2 EXPERIMENTAL

Six loose wool samples, which were dyed under level dyeing conditions with different amounts of Lanasyn Black BRL 200% (Sandoz), were used as references.

Colour measurements were made using a Pacific Scientific Spectrogard Colour Computer System. The specular component of reflectance was excluded. Fibre (3·5 g) was placed in a fibre measurement cell. The CIELAB colour coordinates were determined using Illuminant D_{65} and the 1964 (10°) standard observer data.

The colour specifications of the six reference samples and the virgin wool are given in Table 1.

For each dyeing depth, let us suppose that a specific proportion of fibres are not dyed. Thus, for each dyeing depth, we have varied the proportion of undyed fibres from 10 to 90% of the total loaded fibres. Since the dyeing saturation point of the wool is much higher than the applied percentage of dyestuff, it is obvious that the dyeable areas of the vessel would absorb higher amounts of dyestuff in comparison with the expected (level) dye uptake.

Table 2 gives the actual values of applied dye percentages for dyeable fibres, in the different ratios of dyed and undyed fibres in the dyeing vessel, for different dyeing depths.

Thus, for the simulation of unlevelness, samples were dyed with the percentages given in Table 2. Their colour specifications are given in Table 3. These dyed samples were then blended with the appropriate amount of undyed fibres using a Shirley Analyser.

TABLE 1
The CIELAB Coordinates for Reference Samples

Ref. no.	*Dyestuff (% w/w)*	a^*	b^*	L^*
0	0·00	−2·15	7·40	83·09
1	0·01	−3·00	3·39	75·71
2	0·05	−3·68	−1·03	61·61
3	0·25	−2·97	−4·05	43·89
4	0·50	−2·61	−4·36	36·54
5	1·00	−1·85	−4·21	23·27
6	2·00	−1·38	−3·75	19·40

TABLE 2
Actual Percentages of Dyestuff for the Dyed Fibres in the Vessel when Different Percentages of Fibres Remain Undyed

Ref. no.	*% Appl. dye*	*Percentage of undyed fibres in vessel*								
		10	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
		Actual percentages of dyestuff for dyed fibres								
1	0·01	0·011	0·013	0·014	0·017	0·020	0·025	0·033	0·050	0·1
2	0·05	0·056	0·063	0·071	0·083	0·100	0·125	0·167	0·250	0·5
3	0·25	0·278	0·313	0·357	0·417	0·500	0·625			
4	0·50	0·556	0·625	0·714						
5	1·00	1·111								
6	2·00	2·222								

TABLE 3
CIELAB Coordinates and *Y* Values of Dyed Fibres in Different Percentages

C%	*a**	*b**	*L**	*Y*
0·000	−2·15	7·40	83·09	62·33
0·010	−3·00	3·39	75·71	49·42
0·011	−3·04	3·15	75·15	48·52
0·013	−3·12	2·71	74·09	46·84
0·014	−3·15	2·51	73·58	46·05
0·017	−3·25	1·97	72·16	43·90
0·020	−3·23	1·51	70·86	41·98
0·025	−3·42	0·87	68·91	39·22
0·033	−3·54	0·08	66·20	35·58
0·050	−3·68	−1·03	61·61	29·95
0·056	−3·71	−1·31	61·01	29·26
0·063	−3·73	−1·59	60·14	28·28
0·071	−3·74	−1·86	59·21	27·26
0·083	−3·72	−2·19	58·51	26·50
0·100	−3·61	−2·53	56·83	24·75
0·125	−3·39	−2·89	54·95	22·88
0·167	−3·12	−3·25	51·52	19·72
0·250	−2·97	−4·05	43·89	13·76
0·278	−2·92	−4·12	42·13	12·58
0·313	−2·86	−4·18	40·58	11·60
0·357	−2·79	−4·25	39·54	10·98
0·417	−2·70	−4·31	37·90	10·03
0·500	−2·61	−4·36	36·54	9·29
0·556	−2·53	−4·38	35·05	8·52
0·625	−2·42	−4·34	33·23	7·64
0·714	−2·31	−4·29	29·86	6·18
1·000	−1·85	−4·21	23·27	3·88
1·111	−1·79	−4·18	22·51	3·66
2·000	−1·38	−3·75	19·40	2·84
2·222	−1·36	−3·62	18·98	2·74

The results were then compared with the references. The colour differences between each reference and related simulated unlevel sample are expressed in CIELAB ΔE units.

3 RESULTS

Two quite different problems can arise from unlevelness in loose stock dyeing, i.e. mismatching and colour broken effects. We have considered these two problems separately.

3.1 Mismatching

Tables 4–9 show the colour differences between each reference and the different simulated unlevel dyeings after blending.

In each table, as one would expect, the colour difference between the reference and the unlevel dyeing increases as the proportion of undyed fibres increases. In addition, the colour differences are larger for the darker shades in comparison with the lighter shades.

Table 10 shows the maximum possible amount of undyed fibre for each reference for which the ΔE value between the reference and the simulated unlevel equivalent is less than 2.

As can be seen from the data given in Table 10, it is possible to reproduce Reference no. 1, with an acceptable colour difference, from a dyeing vessel in which only 10% of the fibres have been dyed. This value becomes 70% for Reference no. 2, 30% for Reference no. 3 and 20% for Reference no. 4.

TABLE 4
The CIELAB Coordinates for Different Unlevel Results of Reference no. 1 and the Colour Differences between them and Reference no. 1

Sample	*% Undyed fibres*	a^*	b^*	L^*	ΔE
Reference	0	−3·00	3·39	75·71	0·00
1	10	−2·99	3·42	75·78	0·08
2	20	−2·98	3·42	75·79	0·09
3	30	−2·97	3·43	75·81	0·11
4	40	−2·96	3·43	75·83	0·13
5	50	−2·96	3·43	75·85	0·15
6	60	−2·94	3·45	75·88	0·19
7	70	−2·91	3·51	75·95	0·28
8	80	−2·87	3·55	76·04	0·39
9	90	−2·77	3·74	76·37	0·78

TABLE 5
The CIELAB Coordinates for Different Unlevel Results of Reference no. 2 and the Colour Differences between them and Reference no. 2

Sample	*% Undyed fibres*	*a**	*b**	*L**	*ΔE*
Reference	0	−3·68	−1·03	61·61	0·00
1	10	−3·66	−1·02	61·60	0·03
2	20	−3·62	−0·99	61·71	0·12
3	30	−3·58	−0·91	62·00	0·43
4	40	−3·53	−0·85	62·15	0·59
5	50	−3·46	−0·76	62·34	0·81
6	60	−3·37	−0·62	62·68	1·19
7	70	−3·22	−0·41	63·20	1·77
8	80	−2·97	0·04	64·22	2·91

The effects of the presence of only 10% of undyed fibres for References nos 5 and 6 cannot be eliminated by later blending processes. In other words, the elimination of unlevelness in loose stock dyeing by later blending processes depends on the reference depth. Hence the elimination of unlevelness should be possible for pale shades but very difficult for dark shades.

3.2 Colour broken effects

In a colour broken effect product, the individual colours are still visible in the yarn, after spinning. Whilst it is relatively easy to determine the colour difference for mismatched products, it is not possible to express the colour solidarity of the product in quantitative terms.

The existence of colour broken effects depends on the subjective viewing distance, the colour of the dyed fibres, the difference between the luminance of the dyed and undyed fibres and the fibre diameter. It also

TABLE 6
The CIELAB Coordinates for Different Unlevel Results of Reference no. 3 and the Colour Differences between them and Reference no. 3

Sample	*% Undyed fibres*	*a**	*b**	*L**	*ΔE*
Reference	0	−2·97	−4·05	43·89	0·00
1	10	−2·90	−3·91	44·23	0·38
2	20	−2·82	−3·72	44·66	0·86
3	30	−2·71	−3·51	45·25	1·49
4	40	−2·58	−3·22	45·96	2·27

TABLE 7
The CIELAB Coordinates for Different Unlevel Results of Reference no. 4 and the Colour Differences between them and Reference no. 4

Sample	*% Undyed fibres*	a^*	b^*	L^*	ΔE
Reference	0	−2·61	−4·36	36·54	0·00
1	10	−2·48	−4·11	37·16	0·68
2	20	−2·35	−3·81	37·95	1·54
3	30	−2·18	−3·45	38·92	2·59

depends on the ratio of the components, for example the percentages of dyed and undyed fibres which should be mixed in the later blending processes.

Colour solidarity increases for a blend of pre-coloured fibres as it is viewed from a greater distance. Since the subjective viewing distance is related to the end uses of the dyed product, it is not presently possible to specify the extent of colour broken effects. For example, there is the suggestion of a 2 m distance for the examination of colour broken effects in carpet yarns related to the standing height.[5]

Different colours produce different colour broken effects.[5] Normally colours whose CIE chromaticities are in the same relative colour space will produce more colour solidarity in blends.[5] Since one of the components in the processing of an unlevel dyeing batch is white (undyed fibres), all chromatic colours have more or less the same effect. It should also be noted that fine fibres produce more solid effects than coarse fibres because they blend more intimately.

The effect of the luminance of each component was explored by Guthrie *et al.*[5] for a specific percentage of fibre in the blend. The problem is more complicated for an unlevel dyed product because of the existence of a series of dyed and undyed fibres with different luminances. Obviously, the percentage of each fibre in the blend plays an important role in the creation of colour broken effects.

Since all of the above factors affect colour solidarity, it is not possible

TABLE 8
The CIELAB Coordinates for Different Unlevel Results of Reference no. 5 and the Colour Differences between them and Reference no. 5

Sample	*% Undyed fibres*	a^*	b^*	L^*	ΔE
Reference	0	−1·85	−4·21	23·27	0·00
1	10	−1·40	−3·21	25·46	2·45

TABLE 9
The CIELAB Coordinates for Different Unlevel Results of Reference no. 6 and the Colour Differences between them and Reference no. 6

Sample	*% Undyed fibres*	a^*	b^*	L^*	ΔE
Reference	0	−1·38	−3·75	19·40	0·00
1	10	−0·71	−2·26	23·07	4·01

to judge which simulated unlevel dyed sample given in Tables 3–8 will produce a colour broken effect after blending.

In light depths, for example Reference no. 1, the lightness of the components of a blend of dyed and undyed fibres, when 50% of the fibres in the basket remain undyed, are $L^* = 70{\cdot}86$ ($Y = 41{\cdot}98$) and $L^* = 83{\cdot}09$ ($Y = 62{\cdot}33$), respectively. Since this difference is not too large,[5] solid effects will result after blending. For Reference no. 2, the lightness value for the dyed fibres is $L^* = 56{\cdot}83$ ($Y = 24{\cdot}75$). In this case, the large difference between the lightness values of dyed and undyed fibres will lead to colour broken effects.[5]

4 DISCUSSION

The difference between pale and dark shades originates from the non-linear relationship between the reflectance and the concentration of dyestuffs. As the dyestuff concentration increases, the reflectance initially decreases rapidly. At higher concentrations, the reflectance asymptotically approaches a limiting value. Figure 1 demonstrates this phenomenon for Lanasyn Black BRL 200% (Sandoz) at 600 nm.

Since the concentration of dyestuff is higher for the dyed fibres in an unlevel dyeing in comparison with the level dyed result, the reflectance of

TABLE 10
The Maximum Percentages of Unlevelness which Produce an Acceptable Colour Difference for Different References[a]

Reference no.	*Maximum % undyed fibre*	ΔE
1	90	0·78
2	70	1·77
3	30	1·49
4	20	1·54

[a] Existence of 10% undyed fibres for References nos 5 and 6 lead to $\Delta E = 2{\cdot}45$ and $\Delta E = 4{\cdot}01$, respectively.

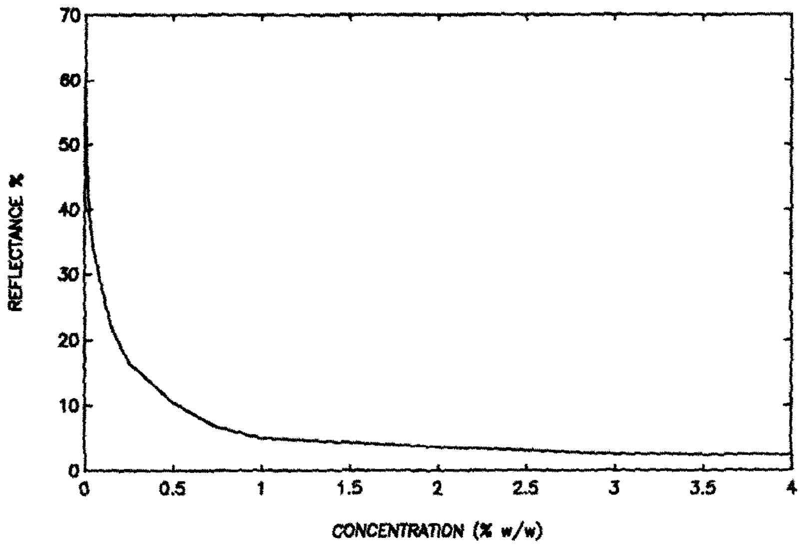

Fig. 1. Reflectance of different concentrations of Lanasyn Black BRL 200% (λ = 600 nm).

the dyed fibres in the batch is less than that for the equivalent level dyed fibres. After the blending of the unlevel dyed product, the reflectance increases and becomes closer to that of the level dyed sample.

For darker shades, since dye concentration variations cause small variations in reflectance (see Fig. 1), there will only be a small colour difference between the dyed fibres in the unlevel batch and the level dyed sample. Hence, after the blending of the unlevel batch, the reflectance of the unlevel product becomes higher than the reflectance of the equivalent level dyed sample.

Gaining an understanding of the colour solidarity effects on unlevel dyed product is not as simple as the understanding of colour tolerance. Many factors, such as the sense of applied colour, thickness, viewing distance and fibre percentage, make colour solidarity too complicated a subject to discuss.

Thus, each unlevel dyed batch should be considered according to the specification of applied fibre, depth, percentage of unlevelness and the end-uses of the product.

It also seems that the opacity of fibres has a role in the creation of colour broken effects. Since textile fibres are not completely opaque, in a blend they can produce a number of different combinations which lead to the formation of a number of colours.[6,7] For a blend which consists of coloured and non-coloured fibres, such as an unlevel dyed product, these different configurations produce different depths. The existence of a series of intermediate colours can both affect colour solidarity and improve it.

5 CONCLUSIONS

High concentrations of dyestuff in dark shades, together with extended dyeing times, normally do not create any unlevelness. However, if unlevelness is created for any reason, the elimination of that unlevelness by blending is difficult to achieve.

On the other hand, while the probability of the creation of unlevelness in stock dyeing is higher for pale shades, it is possible to eliminate this unlevelness by later blending processes. In this case, acceptable colour tolerances and solid effects are achievable in most cases. Hence the risk of the creation of unlevelness in pale shades is minimised by the later gilling and blending processes.

This simulation is based on the existence of only dyed and undyed fibres, which rarely happens in practical dyeing situations. Hence, in practice, where a series of coloured fibres with different depths results from an unlevel dyed batch, the problem should be less evident.

This means that it is possible to optimise the dyeing process using the minimum amount of auxiliaries, full machine loads and the minimum time for increase of temperature.

ACKNOWLEDGEMENT

S. H. Amirshahi is supported by the Isfahan University of Technology (Isfahan, Iran) and this support is gratefully acknowledged.

REFERENCES

1. Cheetham, R. C., *Dyeing Fibre Blends*. D. Van Nostrand, London, 1966.
2. Bird, C. L., *The Theory and Practice of Wool Dyeing*. Dyers' Company Publications Trust, Bradford, 1972.
3. Welham, A. C., In *Wool Dyeing*, ed. D. M. Lewis. Dyers' Company Publication Trust, Bradford, 1992.
4. Beckmann, W., In *The Dyeing of Synthetic Polymer and Acetate Fibres*, ed. D. M. Nunn. Dyers' Company Publication Trust, Bradford, 1979.
5. Guthrie, J. C., Moir, J. & Oliver, P. H., *J. Soc. Dyers and Colour.*, **78** (1962) 27.
6. Burlone, D. A., *Textile Res. J.*, **60** (1990) 162.
7. Amirshahi, S. H. & Pailthorpe, M. T., *Textile Res. J.*, **64** (1994) 357.