

# Spectrophotometric Colour Matching in Melange Fibre Blends

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## Abstract

Colour effect is obtained from mixing different coloured fibres before the blend. In the production of mélange colored textile materials, the incorrect prediction of fibre colors, which will provide the mélange colour desired, constitute a major problem for textile businesses. In this study, an attempt was made at estimating the mix of fibre colours to obtain the mélange colour desired before production. For this purpose, polyester and viscose fibres were used in yellow, red and blue colours. These fibres were obtained in different ratios, three colour mixes and 720 mélange coloured bands. The colour values of these bands measured by a spectrophotometer were expressed in CIELab 1976 units. The Stearns – Noechel model was the basis for colour forecasting. A new approach has been developed for calculating coefficient  $M$  in the model. This approach results in each mixture, and a different coefficient  $M$  was calculated for all the wavelengths in the range 400 - 700 nm. Colour calculations were made using the  $M$  coefficients. The average colour difference between the colour values measured and those calculated were found to be 0.95 CIE-Lab units. This result suggests that in fibre blends, estimating the colour of the Stearns – Noechel model might be a sufficient result.

**Key words:** mélange, reflectance, viscose, polyester, Stearns-Noechel.

## Introduction

Mélange colour work, which is made to provide special colour effects in textiles, is prominent over a large area. To produce mélange coloured fibres, first different coloured fibres are mixed prior to blending, and then a different colour effect is achieved. In this mixture, one of the biggest problems is not to obtain the colour of mélange desired. Estimating the colour for a given colour standard for coloured fibres in a mix will be of great benefit to businesses in terms of time and cost.

The Kubelka – Munk theory is widely used in the estimation of yarn and fabric colour by spectrophotometers. However, this theory does not give satisfactory results in the prediction of mélange coloured fibres [1]. Many scientific studies have been made on mélange colour forecasting, the Stearns – Noechel model being one of the most important.

Aspland and Zhou [2] tried to predict if the fibre colour depends on the fibre mixing method. For this they prepared a fibre mixture of black and white polyester fibre in a 50/50 ratio using eight different ways. Their studies were based on the Stearns – Noechel model and found the experimental constant  $M$  to be 0189. Invernizzi and colleagues [3] based their work on Friel's theoretical model in an attempt to guess the colour of fibres using 17 pieces of cotton fibres as thin as 0.2 tex. The colour difference was found to be greater than  $\Delta E = 1$ . Invernizzi and colleagues [4] prepared 234 pieces of blends using 13 different

colours of cotton fibre as thin as 0.2 tex. The  $M$  constant in the Stearns – Noechel model was identified as depending only on the wavelength, and 27% of the mixtures prepared were said to be  $\Delta E \leq 1$ . Rong and Feng [5] prepared 54 pieces of viscose blends in their studies. They used the Stearns – Noechel model in their work and proposed a new method to calculate  $M$  empirical constants. By this method, they found the  $M$  coefficient to be 0.09 and used as a constant value.

In the Stearns – Noechel model, for calculating the  $M$  coefficient that can best estimate the colour in fibre blends, different methods have been developed in previous studies. Rong [6] calculated the  $M$  coefficient according to an analysis of media. Invernizzi and colleagues [3] stated that the  $M$  coefficient was linearly related to the wavelength, shown in **Equation 1**.

$$M = \frac{1}{1000}(0.12\lambda + 42.75) \quad (1)$$

In this study, to predict the fibre colours of three colour polyester / viscose mélange fibre blends, the Stearns – Noechel model was used. To calculate the  $M$  coefficient in the model, a new approach was made, in which a different  $M$  coefficient was calculated for each mixture at intervals of 400 - 700 nm for each 10 nm. With the  $M$  coefficients, we attempted to estimate the colour values of 720 pieces of Polyester and Viscose mélange coloured bands. The reflectances of the 720 pieces of mélange coloured bands prepared were measured by a spectrophotometer. Then the  $M$  coefficients were determined close

to the reflectance values measured using the Stearns – Noechel model. Using these  $M$  coefficients, reflectance calculations were made once again. The colour difference was found using the measured and calculated reflectance values, expressed in CIELab 1976 units.

## Stearns - Noechel model

Stearns and Noechel developed a model for fine mixed wool in published research in 1944 (**Equation 2, 3, 4**). In this model, the  $M$  coefficient was found to be 0.15 [5].

$$F(R) = \frac{1-R}{[M(R-0.01)+0.01]} \quad (2)$$

$$F(R_{mix,\lambda}) = \sum_i x_i F(R_{i,\lambda}) \quad (3)$$

$$\sum_i x_i = 1 \quad (4)$$

where:

- $R$  - reflectance (fraction (decimal) species,  $R = 15\%$  of the sample,  $R = 0.15$  is)
- $R_{mix,\lambda}$  - colour reflectance of the mixture prepared according to wavelength,
- $x_i$  -  $i$ th fibre mixture ratio (in terms of fractions)
- $M$  - dimensionless constants.

In this study, the following equation was used, assuming three-colour mixing.

$$F(R_{mix}) = x_1 F(R_1) + x_2 F(R_2) + x_3 F(R_3) \quad (5)$$

Moreover, the fibre mixture ratio of the sum should be equal to 1.

$$x_1 + x_2 + x_3 = 1 \quad (6)$$

### Calculation of the coefficient M

In this study, a new approach is proposed of calculating the *M* coefficient. In previous studies, the *M* coefficient was adopted as a constant value regardless of the mixture and wavelength. In this study, for every mixture and 10 nm wavelength increase between 400 - 700 nm, a separate *M* coefficient was calculated. The *M* coefficient was changed in each wavelength with an increase of 0.0001, between 0.0001 and 2, and the *F(R)* function was calculated by replacing each *M* value in **Equation 2** (total: 20000 calculations). For each mixture, for the same wavelength, by placing the *F(R)* values calculated in **Equation 5**, the *F(R<sub>mix</sub>)* function of the mixture was calculated. The *M* value, which makes the absolute difference the smallest between the reflectance values measured and those calculated, was determined as the true *M* value.

Table 1. Fibre properties.

Colors	Viscose fibre			Polyester fibre		
	finesse, dtex	length, mm	label	finesse, dtex	length, mm	label
Blue	1.7	40	Lenzing	1.7	38	Sasa
Red		38				
Yellow		40				

Table 2. Blends prepared.

Blend number	Mixture code	Mixture Name	Number of mixtures (Item)
1	PPP_RYB	Red Polyester / Yellow Polyester / Blue Polyester	1....36
2	PPV_RYB	Red Polyester / Yellow Polyester / Blue Viscose	1....36
3	PVP_RYB	Red Polyester / Yellow Viscose / Blue Polyester	1....36
4	VPP_RYB	Red Viscose / Yellow Polyester / Blue Polyester	1....36
5	VVV_RYB	Red Viscose / Yellow Viscose / Blue Viscose	1....36
6	VVP_RYB	Red Viscose / Yellow Viscose / Blue Polyester	1....36
7	VPV_RYB	Red Viscose / Yellow Polyester / Blue Viscose	1....36
8	PVV_RYB	Red Polyester / Yellow Viscose / Blue Viscose	1....36
9	PVP_RRY	Red Polyester / Red Viscose / Yellow Polyester	1....36
10	VPV_RRY	Red Viscose Red Polyester / Yellow Viscose	1....36
11	PVP_RRB	Red Polyester / Red Viscose / Blue Polyester	1....36
12	VPV_RRB	Red Viscose / Red Polyester / Blue Viscose	1....36
13	PVP_BBY	Blue Polyester / Blue Viscose / Yellow Polyester	1....36
14	VPV_BBY	Blue Viscose / Blue Polyester / Yellow Viscose	1....36
15	PVP_BBR	Blue Polyester / Blue Viscose / Red Polyester	1....36
16	VPV_BBR	Blue Viscose / Blue Polyester / Red Viscose	1....36
17	PVP_YYB	Yellow Polyester / Yellow Viscose / Blue Polyester	1....36
18	VPV_YYB	Yellow Viscose / Yellow Polyester / Blue Viscose	1....36
19	PVP_YYR	Yellow Polyester / Yellow Viscose / Red Polyester	1....36
20	VPV_YYR	Yellow Viscose / Yellow Polyester / Red Viscose	1....36
<b>Total</b>			<b>720</b>

Table 3. Fibre mixture ratio.

Fibre type	Fibre ratios in the mixture, %																	
	1	2	3	4	5	6	7	.	.	.	.	30	31	32	33	34	35	36
1. Fibre	10	10	10	10	10	10	10	.	.	.	.	50	60	60	60	70	70	80
2. Fibre	10	20	30	40	50	60	70	.	.	.	.	40	10	20	30	10	20	10
3. Fibre	80	70	60	50	40	30	20	.	.	.	.	10	30	20	10	20	10	10

### Calculation of colour differences

To express the colour numerically, the light source, object and observer should also be defined numerically. The light source, with the values of the Spectral Energy Distribution (SED), the properties of the objects, % reflectance values and the properties of the Standard Observer is defined as colour matching functions (colour-sensitivity values) called X, Y, Z tristimulus values [1].

In 1976, the CIE (Commission Internationale de l'Eclairage, International Lighting Commission) defined a system that was calculated from tristimulus values X, Y and Z in the form of three coordinate - *L\**, *a\** and *b\** and is called the CIELab system [7]. In this system, *L\** describes brightness, *a\** describes red-green, *b\** describes yellow-blue, and *C\** describes chroma (a point distant from

the neutral point, the colour saturation), and the rotation speed *h* is used to define colour tones.

The colour difference denominated in units of CIELab is calculated using the following formula [8].

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

Here  $\Delta$  shows the difference.

## Experimental study

### Materials

In the study, the following material colours were used: yellow, red and blue types of viscose and polyester fibres, the properties of which are given in **Table 1**.

### Preparation of mixed fibre

Fibre blends was made using a Trash Analyser with Microdust SDL MDTA Rotor Attachment 3. To obtain a homogeneous colour, the fibre was put in the machine three times. The weight of each mixture of fibre was 5 grams. All the fibre blends were of red, yellow and blue colour. The blends were prepared in the form of 20 pieces using 100% Polyester, Polyester/Viscose and 100% Viscose. Each blend was prepared in the form of 36 pieces, using different proportions of red, yellow and blue colours. Thus, mélange color bands were obtained in a total 720 pieces in 20 blends (**Table 2**). The fibre mixture ratios of 36 pieces are shown in **Table 3**.

For example, if the 1<sup>st</sup> blend is expressed as a 1<sup>st</sup> mix ratio, the 1<sup>st</sup> fibre is red polyester fibre (10%), the 2<sup>nd</sup> fibre is yellow polyester fibre (10%) and the 3<sup>rd</sup> fibre is blue polyester fibre (80%).

### Colour measurement

In the colour measurement of the mélange coloured stripes prepared, a Minolta 3600 D spectrophotometer was used. From 30 points (10 nm each between 400 nm and 700 nm) reflectance values were measured and recorded. The reflectance brightness component (specular component) was included. In the measurements, the representative sample was sensitive, for example, during the measurement, non-strict protruding fibres were used. To ensure sufficient accuracy, 25.4 mm was chosen, which was the largest measuring range in the spectrophotometer. In the experiment, glass was not

**Table 4.** *M* coefficients calculated; *WL* - Wavelength ( $\lambda$ , nm)

WL	Blend number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
400	0.17	0.32	0.32	0.17	0.14	0.12	0.27	0.22	0.24	0.23	0.87	1.44	0.18	0.15	0.24	0.05	0.20	0.22	0.24	0.23
410	0.18	0.51	0.35	0.19	0.10	0.20	0.21	0.14	0.27	0.28	1.25	0.19	0.12	0.10	0.12	0.03	0.24	0.18	0.30	0.28
420	0.18	0.16	0.35	0.19	0.10	0.21	0.06	0.11	0.30	0.33	1.49	0.10	0.02	0.09	0.05	0.05	0.26	0.12	0.36	0.31
430	0.26	0.16	0.49	0.15	0.11	0.20	0.03	0.11	0.18	0.32	1.25	0.11	1.03	0.10	0.04	0.06	0.33	0.11	0.41	0.36
440	1.46	0.14	0.74	1.28	0.13	0.37	0.01	0.11	0.08	0.41	1.25	0.11	1.03	0.14	0.08	0.09	0.50	0.11	0.56	0.46
450	0.27	0.10	1.17	1.28	0.14	0.68	0.00	0.11	0.03	0.54	1.04	0.12	1.60	0.19	0.12	0.11	0.54	0.13	0.82	0.47
460	0.40	0.04	1.78	1.90	0.19	1.36	0.47	0.08	0.10	0.28	1.36	0.15	1.04	0.25	0.18	0.27	0.58	0.16	0.90	0.37
470	0.13	0.12	1.33	0.02	0.44	1.72	0.03	0.10	0.06	0.11	1.28	0.17	1.08	0.66	0.43	1.18	0.22	0.19	0.38	0.28
480	0.19	0.25	1.13	0.22	0.30	0.18	0.28	0.07	0.23	0.17	1.20	0.02	0.23	1.94	0.31	1.52	0.24	0.31	0.26	0.31
490	0.16	0.20	1.93	0.20	0.17	1.95	0.22	0.18	0.19	0.30	1.92	1.73	0.19	1.93	0.46	1.94	0.21	0.24	0.21	0.24
500	0.14	0.17	1.36	0.16	0.09	1.94	0.18	0.09	0.16	0.33	1.20	1.04	0.16	0.10	0.84	1.84	0.17	0.20	0.18	0.21
510	0.14	0.16	1.94	0.16	0.08	0.00	0.17	0.11	0.16	0.00	1.84	0.04	0.15	0.07	1.93	1.03	0.16	0.19	0.17	0.20
520	0.14	0.16	1.34	0.16	0.08	0.04	0.17	0.10	0.16	0.04	1.94	0.12	0.16	0.05	1.54	1.80	0.16	0.18	0.17	0.20
530	0.14	0.16	1.37	0.17	0.09	0.07	0.17	0.02	0.16	0.07	1.92	1.25	0.16	0.08	1.04	1.20	0.16	0.19	0.17	0.20
540	0.14	0.16	1.93	0.16	0.10	0.06	0.17	0.04	0.16	0.08	1.34	0.59	0.16	0.09	1.50	1.29	0.16	0.18	0.17	0.20
550	0.14	0.16	1.30	0.16	0.10	0.06	0.17	0.05	0.16	0.09	1.46	0.42	0.16	0.08	0.87	1.98	0.16	0.18	0.17	0.19
560	0.14	0.16	0.02	0.17	0.10	0.08	0.17	0.09	0.16	0.13	1.38	0.44	0.16	0.09	0.61	1.93	0.17	0.18	0.17	0.20
570	0.14	0.17	0.04	0.17	0.12	0.07	0.17	0.15	0.17	0.17	0.66	0.38	0.17	0.10	0.41	1.26	0.17	0.18	0.18	0.20
580	0.15	0.18	0.13	0.17	0.10	0.02	0.18	0.21	0.19	0.31	0.39	0.29	0.17	0.10	0.31	1.00	0.17	0.19	0.21	0.22
590	0.15	0.19	0.18	0.18	0.09	0.03	0.19	0.22	0.43	0.29	0.19	0.19	0.17	0.11	0.24	0.08	0.17	0.19	0.26	0.45
600	0.16	0.19	0.19	0.15	0.08	0.05	0.17	0.22	0.22	0.16	0.11	0.13	0.17	0.12	0.22	0.07	0.17	0.19	0.31	0.39
610	0.16	0.20	0.18	0.14	0.08	0.05	0.17	0.21	0.24	0.13	0.10	0.13	0.17	0.12	0.20	0.07	0.18	0.20	0.32	0.28
620	0.16	0.20	0.18	0.14	0.08	0.05	0.17	0.20	0.18	0.17	0.12	0.13	0.18	0.12	0.19	0.08	0.18	0.20	0.33	0.29
630	0.16	0.20	0.17	0.14	0.09	0.05	0.17	0.20	0.10	0.18	0.12	0.14	0.18	0.14	0.19	0.08	0.18	0.20	0.34	0.29
640	0.16	0.20	0.17	0.13	0.09	0.05	0.17	0.20	0.27	0.16	0.11	0.14	0.18	0.14	0.19	0.08	0.18	0.20	0.34	0.27
650	0.16	0.21	0.18	0.12	0.09	0.06	0.16	0.20	0.03	0.12	0.09	0.13	0.18	0.16	0.20	0.08	0.18	0.21	0.35	0.24
660	0.16	0.21	0.18	0.11	0.09	0.06	0.15	0.21	0.22	0.11	0.08	0.12	0.19	0.16	0.20	0.08	0.19	0.21	0.36	0.21
670	0.16	0.21	0.17	0.11	0.10	0.07	0.15	0.21	0.34	0.11	0.08	0.12	0.19	0.17	0.20	0.09	0.19	0.22	0.36	0.20
680	0.16	0.22	0.18	0.11	0.10	0.07	0.15	0.22	0.22	0.11	0.08	0.12	0.19	0.17	0.20	0.09	0.18	0.22	0.37	0.20
690	0.16	0.23	0.18	0.11	0.10	0.07	0.15	0.23	0.11	0.11	0.08	0.12	0.19	0.18	0.21	0.09	0.18	0.23	0.37	0.19
700	0.16	0.26	0.18	0.11	0.10	0.07	0.16	0.25	0.11	0.12	0.09	0.13	0.20	0.17	0.23	0.09	0.19	0.25	0.39	0.20

**Table 5.** Values of the mean value of error between the measured and predicted reflectance values according to the wavelength of the fibre blend; *WL* - Wavelength ( $\lambda$ ; nm).

WL	% Error mean values according to harman type																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
400	0.98	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87
410	1.12	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88
420	1.15	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90
430	1.25	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98
440	1.27	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11
450	1.36	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93
460	1.44	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91
470	1.55	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87
480	1.29	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88
490	1.12	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90
500	1.14	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98
510	1.24	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11
520	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93
530	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91
540	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87
550	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88
560	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90
570	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98
580	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11
590	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93
600	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91
610	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87
620	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88
630	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90
640	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98
650	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11
660	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93
670	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91
680	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87
690	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88	1.11	0.87	0.98	0.91	0.90	0.93	0.88
700	0.8																			

**Table 6.** Average values of the difference between the measured and calculated colour values of the fibre blends; P - Polyester V - Viscose R - Red Y - Yellow B - Blue.

Mixture Name	Average value of colour differences					
	$\Delta L^*$	$\Delta a^*$	$\Delta b^*$	$\Delta C^*$	$\Delta H$	$\Delta E$
PPP_RYB	0.0110	-0.0255	0.1149	0.0710	0.1897	0.5638
PPV_RYB	-0.0184	-0.0160	0.1044	0.0625	0.0456	0.6994
PVP_RYB	-0.0804	0.1368	-0.1377	0.0031	0.0275	0.6726
VPP_RYB	-0.1576	-0.6712	-0.2538	-0.8572	0.0413	2.5288
VVV_RYB	0.0152	-0.0482	0.0280	-0.0758	0.0161	0.3638
VVP_RYB	0.0016	-0.0258	0.0062	-0.0493	0.0205	0.3793
VPV_RYB	-0.1574	-0.7096	-0.1663	-0.6046	0.1399	2.0341
PPV_RYB	-0.0381	-0.0235	-0.1205	-0.0863	0.0354	0.5315
PVP_RRY	0.2292	1.0773	0.4578	1.0600	0.0136	1.6876
VPV_RRY	-0.0166	-0.0090	0.0089	-0.0181	0.0108	1.0148
PVP_RRB	0.0470	-0.1313	-0.2214	-0.1555	0.0168	1.2621
VPV_RRB	-0.0438	-0.0569	-0.0335	-0.0327	0.0266	1.2332
PVP_BBY	-0.0684	0.0404	0.0515	-0.1206	0.1140	0.4929
VPV_BBY	-0.0048	0.0250	-0.0476	-0.1406	0.1290	0.3686
PVP_BBR	0.0281	-0.0711	0.0071	-0.1713	0.0163	0.3710
VPV_BBR	0.0089	-0.2100	0.0027	-0.2732	0.0188	0.6010
PVP_YYB	-0.1102	-0.0336	-0.1556	-0.1318	0.0359	1.0523
VPV_YYB	-0.0631	-0.0519	-0.0464	0.0678	0.0377	0.6099
PVP_YYR	0.0150	0.0300	0.0609	0.2723	0.1917	0.9059
VPV_YYR	-0.1049	-0.2913	-0.0967	-0.1713	0.0281	1.7321

used to keep the samples or cover them. For all the samples measured, at least 10 readings were taken carefully from different samples at random until the colour difference was  $<0.2$  CIELab 1976 (D65 light source and observer  $10^\circ$ ). Measurements larger than 0.2 (CIELab 1976) between the measured values and average of the previously measured colour difference were not evaluated. The averages of the other values were recorded as correct reflectance values.

## Results

To achieve optimum results in the equation, the Stearns – Noechel model must depend on the  $M$  coefficient. In this study, according to the method proposed, a was developed to calculate the  $M$  coefficient for each mix; a separate  $M$  coefficient was calculated at each wavelength (Table 4, see page 127).

The% error of the average between the measured and calculated  $M$  coefficients of the mixtures of the fibre prepared and the reflectance values predicted is given in Table 5. The mixture with the highest average% error is red polyester / yellow polyester / blue polyester (PPP\_RYB) with 1.0567 (average wavelength). The mixture with the lowest average% error is red viscose / yellow viscose / blue polyester (VVP\_RYB), with 0.9353. In general, the differences between the

measured and calculated reflectance values were low.

Colour differences were calculated using the formula CIELab 1976 ( $10^\circ$  D65 standard illuminant and observer). Using the measured reflectance values and  $M$  coefficients in Table 4, colour differences ( $\Delta E$ ) between the Stearns – Noechel equation and the reflectance values calculated are shown in Table 6. Moreover, colour information in the form of  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C^*$  and  $h$  is also given. On average, the colour becomes darker in the whole mixture. Green and blue colour values of the colour value predicted become larger than those measured. In addition, a reduction occurred in the colour saturation. The average difference between the measured and estimated total color values is  $\Delta E = 0.9552$  CIELab units. The highest difference was obtained for  $\Delta E = 2.5288$  CIELab unit and the red viscose / yellow polyester / blue polyester (VPP\_RYB) mixture. The lowest difference was obtained for the mixture of red viscose / yellow viscose / blue viscose (VVV\_RYB), in which all fibre types in the mixture were of viscose fibre and  $\Delta E = 0.3638$  CIELab unit. In the majority of mixing,  $\Delta E$  was below 1 out, which is an acceptable limit.

## Conclusion

In this study, the Stearns – Noechel model was used to develop a new approach

for calculating the  $M$  coefficient in the model.  $M$  coefficients calculated by this new approach were used for estimating the colour of 720 pieces of mélange colored band. The  $M$  coefficient in the Stearns – Noechel model depends on the final colour of the mixture. Previous studies usually calculated one  $M$  coefficient only. In this study, the  $M$  coefficient was calculated separately for each mixture and wavelength. By calculating the colour difference between the measured colour values and estimated colour values based on the new method, CIELab 1976 was expressed (D65 light source and observer  $10^\circ$ ). The average colour difference is 0.95 CIELab units, which shows that the new method, developed for calculating the coefficient  $M$  in the Stearns - Noechel model for the mélange of color mixing, can estimate colour values with sufficient accuracy.

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