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New Approach to Achieve Non-metameric Colour Matching in Textiles

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ABSTRACT

Metamerism is one of the most essential perceptual phenomena of the visual system and has been widely premeditated. Metamerism is the colour variation perceived when the viewing conditions like light source (illuminant), viewing angle, different observer or distance from the observer are changed. Metamerism plays major role in the industries like textile, plastic, paint etc., where colour matching is inevitable. Even though there are different types of metamerism arises in the field of colour matching, most of the importance are given to the illuminant metamerism.Many recipeare developed at laboratory level to minimize the metamerism with respect to cost and requirement. The present studydeals with the non-metameric colourmatching in order to attainthe spectral match.The loop hole that has been found to achieve the objective is matching the spectral curve of the target within the limits in which the human eye cannot differentiate the colour variation. Though superimposition of spectral curves of the target and match are impossible, until the dyes that are used on the target are used over the match. From the experiment, non-metameric colour matching was achieved about 70% of the samples that give ΔE value less than 1. For remaining 30% of the samples, the dye chosen are not suitable to predict the precise colour recipe.

Keywords: Metamerism, Colour matching, illuminant, dyeing, spectral match, reflectance, reactive dyeing

INTRODUCTION

The CIE system of colour matching functions as that of the human visual system. It has developed many systems to acquire a colour recipe that can match the target with one or more illuminants. The occurrence of metamerism is due to many factors say change of illuminant, change of viewing angle, change of instruments etc. There are different types of metamerism like illuminant, observer, field size and geometric were recognized [6,31]. Among them 'illuminant metamerism' was considered more [9]. In general, the metamerism is nothing but, when two colours match under one set of conditions and fail to match when the conditions are changed [11,31]. As per CIE definition of metamerism, a property of colour stimuli that are spectrally different and have same tri-stimulus values [31,42]. For an example, a pair of textile samples, which match under one illuminant may or may not match under other illuminants (figure1). This effect is known as 'Illuminant Metamerism' [6,42]. When this happens the spectral reflectance curves of the two specimens A & B are different (figure 2) but their tri-stimulus values under one illuminant (say at illuminant D65) happen to be identical[31].

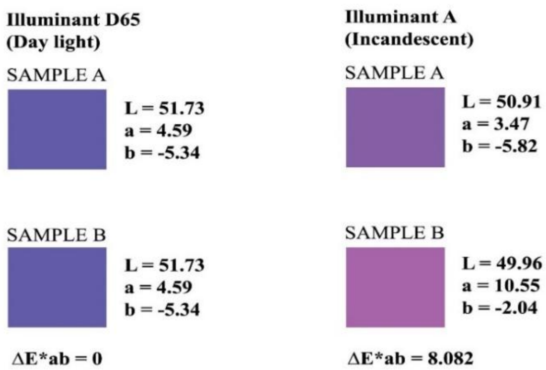

Figure 1: Change in L* a* b* Values due to Illuminant Metamerism

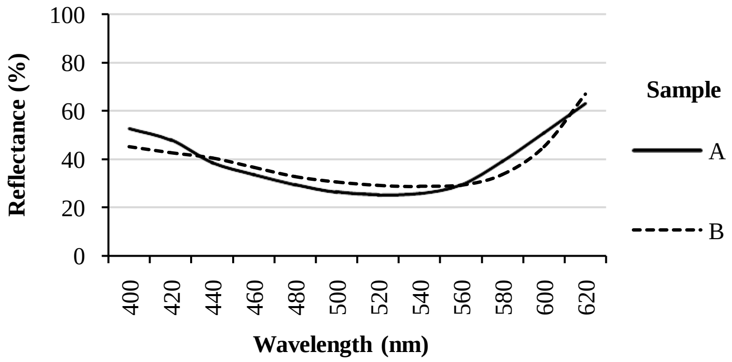

Figure 2: Spectral Reflectance Graph of Sample A and Sample B at Illuminant A

Thus in case of sample A & B, the metamerism occurs while they were matched under illuminant A but not under the illuminant D-65. This may be due to many reason, but most of the cases occurs because of not using the same dyes to match the target, as it is very difficult to know about the dyes that have used on the target too.

Different approaches were developed in determining the indices of metamerism or degree of metamerism [28,31,32]. ISCC found in 1967 [10], there were fourteen general indices of metamerism were expressed [11,15,33]. William A.Thornton [33] studied about the spectral power distribution (SPDs) of CIE standard illuminants (figure 3) that match to the 1964 CIE standard observer, and spectral reflectance distribution of sets of object that reflects matching lights[33].

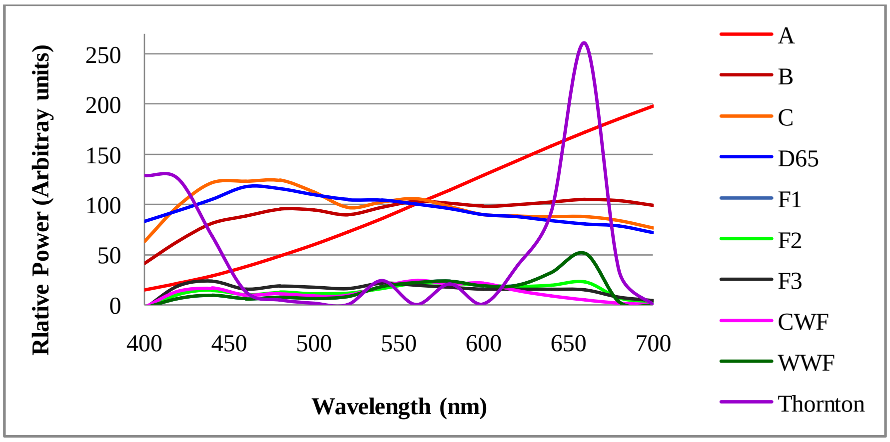

Figure 3: Spectral Power Disribution of CIE Illuminants

(Data for the graph collected from ref. no. 42)

In conventional method of colour matching they try to keep the level of metamerism to a minimum by computing the metameric index between the target and match and discarding recipes of match that have a high index value[33]. Further the supplier and customer decide on the illuminants that are used while matching the colour. Easiest way to get non-metameric match is to use the same dyes as in the target. When two dyes combinations are used in the recipe, there is no guarantee that the match not to be metameric [31].

ColourDifference Calculation Formula:

Formation of colour measurement committee formed in the year 1963[42]. The formulae defined the colour difference in a uniform colour spacing. The CIE simplified it and introduced in 1976 as L*, a*, b* which later becomes a famous as CIELAB [7,8,9] and used all over the industries. Then the rectangular coordinates were converted to cylindrical form with hue angle [8, 15, 20].

The equations for the calculation of colour differences are defined on the basis of theoretical conclusions, experience and experimental results. The total colour difference (ΔE) can be calculated by the following formula [10,12,20,42].

$$\Delta E^* = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \quad (1)$$

Where,

ΔE = Total colour difference

L_1^* = Lightness of sample

L_2^* = Lightness of standard

a_1^* = Redness/Greenness of sample

a_2^* = Redness/Greenness of standard

b_1^* = Yellowness/Bluenessof sample

b_2^* = Yellowness/Blueness of standard

Apart from this, other advanced formulas were also found (CIELAB, CIE94, CMC and CIEDE2000) and utilised [7,21]. The CIE recommended the CIELAB for object colours and CIELUV for illuminating colours [1]. But most widely the previous one shown above (CIELAB)was used most of the industries still to calculate the index of metamerism. The same formula was used in this work too to calculate the colour difference value (ΔE). Sometime visual interpretation of metamerism is found using the grey scale [1].On the other hand, the CIE also provides the sets of spectral distributions for standard observer and the inter observer variability was measured using the chromaticity coordinates [14,18]. The following work also concentrates on the observer metamerism and found that is nullified.

EXPERIMENT

The work has been carried out using Reactive HE brand dyes. A data bank was created using different colours from light to dark shades say 0.1% to 4.0%. Ten different shades were produced per dye and the same was repeated for three times to get repeatability. Importance is given to the primary colours (Red, Yellow and Blue) that used to match the target. The reflectance values of these dyed sampleswere measured using spectrophotometer[30,42]. Measurement were carried out at different places of a sample to average out and same is used to calculate the slope values. These tabulated values are used as the database for running the computer program that predict the recipe for dyeing the sample which is to be matched with the target. This program was designed in such a way that, it calculates the dye recipe that fulfills the objective of the experiment. The program was written in BASIC language and runs once, the tolerance values are given as input. As the tolerance limit (upper and lower) are increased, as shown in the figure 4, the number of recipe will be more. But it should not exceed the greater than 1 % which may leads to more colour variation that can be easily differentiated by a human eye.

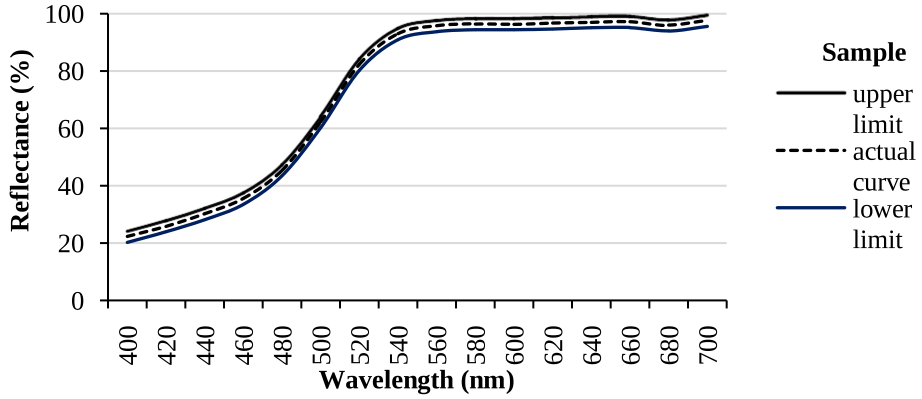

Figure 4: Reflectance Band Width and Actual Curve of C.I. Yellow HE4R

Dyes and Dyeing:

As the reactive dyes are widely used to dye the cotton material, the same was used in the experiment as shown in the table 1. These dyes were procured from COLOURTEX. The dyeing was carried out as described in the figure 5. The recipe used to dye the samples are given in the table 2.

Table 1: List of Dyes Used to Prepare the Database

Blue Dyes	Yellow Dyes	Red Dyes	Other Dyes	
N. Blue HER H/C C.I. Re. Bl. 171	Yellow HE4G C.I. Re. Yel. 81	Red HE3B-N C.I. Re. Red 120	T. Blue H5G C.I. Re. Blue 25	Orange HER C.I. Re. Org. 84
Blue HEGN C.I. Re. Bl. 198	G. Yellow HE4R C.I. Re. Yel. 84	Red HE7B C.I. Re. Red 141	Violet 5R C.I. Re. Viol. 5	Black HN C.I. Re. Blk.8

Table 2: Dyeing Parameters

% of Shade	0.1	0.3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
NaCl (g/l)	20		30		50	60		80	80	90
Na_2CO_3 (g/l)	10		15		15	15		15	20	25
Temperature	80°C									
l:m ratio	40:1									
Dyeing Time	90 minutes									

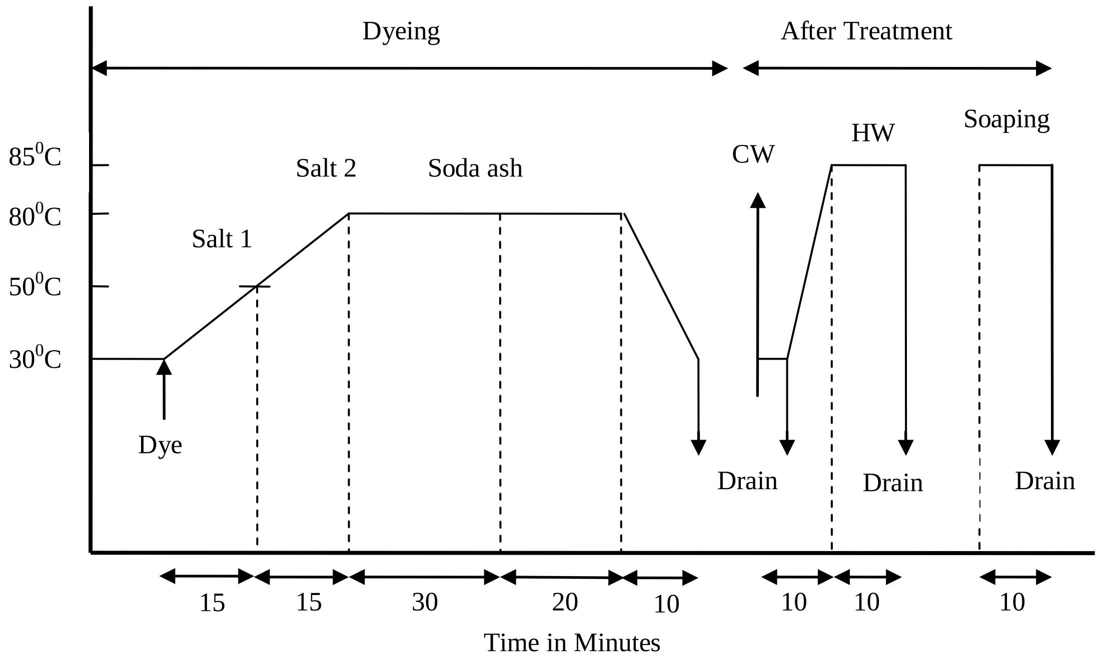

Figure 5: Dyeing Procedure for HE Dyes

Measurement of Reflectance:

Before taking the measurement, the spectrophotometer was calibrated using a standard white and black tile.The sample, which was folded four times, to be sure of being optically opaque was placed over the instrument port and the scanning was done.After the completion of the scanning, the reflectance values (R) from 400 nm to 700 nm at 20nm intervals were printed out. Hence, 16 values were obtained for each sample at 16 different wavelengths. The above procedure is repeated five times at five different area in a sample.Average reflectance value (R) is calculated for the 16 wavelengths from 400 nm to 700 nm are tabulated. An example measured reflectance values are shown in the table 3. And the respective dye structure (figure 6) of Navy Blue HER (C.I. No.171, Molecular Formula: $C_{40}H_{23}Cl_{2}N_{15}Na_{6}O_{19}S_{6}$, Molecular Weight: 1418.93 and CAS Registry Number: 77907-32-5) is shown below.

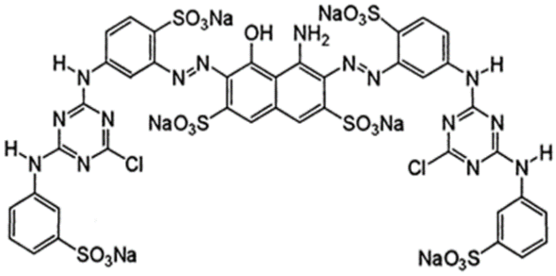

Figure 6: Chemical structure of C.I. Reactive Blue 171

(ref. http://www.worlddyevariety.com/reactive-dyes/reactive-blue-171.html)

Table 3: Reflectance Values of Blue HER at Various Shade (%)

	0.1	0.3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
400	78.76	73.12	64.67	58.42	50.13	45.03	40.42	36.63	33.24	31.35
420	76.49	70.49	62.23	55.88	47.81	42.93	38.48	34.74	31.58	29.68
440	75.58	69.33	60.88	54.42	46.43	41.55	37.19	33.47	30.36	28.59
460	74.57	68.15	59.52	53.05	45.03	40.15	35.83	32.14	29.13	27.34
480	73.15	66.38	57.67	51.14	43.06	38.2	33.95	30.33	27.40	25.71
500	70.63	63.54	54.55	48.11	40.03	35.35	31.18	27.61	24.82	23.26
520	67.86	60.38	51.24	44.99	37.06	32.49	28.42	25.00	22.36	20.87
540	62.68	54.81	45.54	39.35	31.63	27.29	23.52	20.39	18.02	16.72
560	57.14	48.78	39.46	33.44	26.06	22.09	18.71	15.89	13.88	12.8
580	52.69	44.22	34.94	29.09	22.08	18.41	15.39	12.89	11.16	10.24
600	49.81	41.12	32.02	26.25	19.6	16.1	13.36	11.13	9.60	8.76
620	48.99	40.15	31.18	25.4	18.76	15.39	12.75	10.61	9.16	8.32
640	50.29	41.31	32.26	26.24	19.61	16.16	13.39	11.21	9.70	8.88
660	59.21	50.03	40.67	33.89	26.52	22.54	19.15	16.39	14.47	13.22
680	73.18	65.24	56.45	49.29	41.35	36.58	32.54	29.05	26.41	24.53
700	87.29	82.59	76.35	70.54	63.56	58.84	54.68	51.11	47.86	45.55

After the tabulation, the graph plotted will give an idea about the uniform dyeing and shade difference between the samples, which is shown in the figure 7.

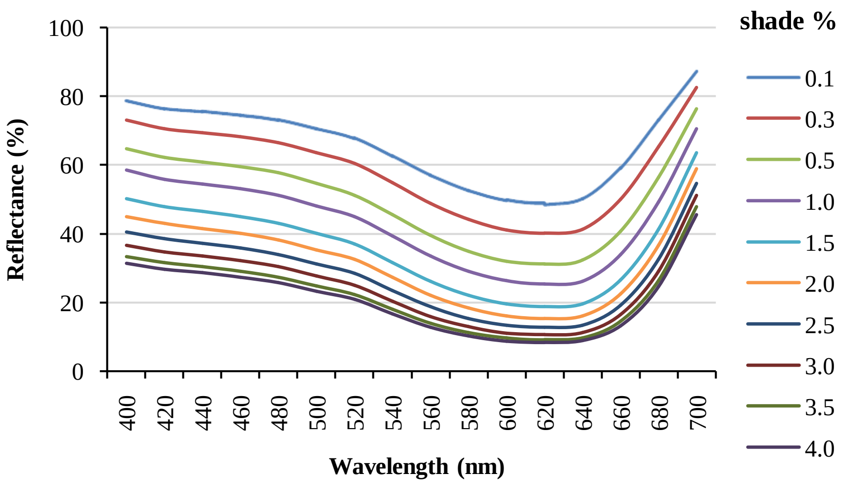

Figure 7: Reflectance Curves of N. Blue HER at Various Concentration

Similar procedure was carried out for all other dyes that was given in the table 1. From from the measured reflectance value, K/S values are calculated using the formula (2) and the alpha values are calculated using the formula (3) as given below.

These reflectance values are used to calculate the K/S_λ values by the formula [23,41]:

$$K/S_{\lambda} = \frac{(1 - r_{\lambda})^2}{2r_{\lambda}} \qquad (2)$$

Where,

‘ r_λ’ is the reflectance fraction i.e. ($R\%_\lambda$ /100) at the wavelength ‘λ’.

The dyeing absorbency coefficient alpha (α_λ) is defined as the rate of change of K/S_λ as concentration changes [42].

$$\alpha_{\lambda} = \frac{((K/S_{\lambda\_dyed}) - (K/S_{\lambda\_blank}))}{Dye\_Concentration} \quad (3)$$

Alpha is sometimes referred to as the ‘normalized K/S value’. Thus, 16 α_λ values are obtained for each of the dyes. A total of 160 values for 10 dyes.

Formulating the Program:

A software program was written using the BASIC language. The reason for selecting this language is that it is easy to use and suitable for this type of work. The databank of all colourants and the reflectance values of the targets was the input data for this program.The calculations were done using the linear programming algorithm. The reason behind choosing this algorithm was that since the K/S_{λ} values are linearly additive 'L.P.' is the simplest approach, especially when a standard "Simplex Method" subroutine for solving 'L.P.' problems was available.

Consider a target sample whose reflectance values in the visible wavelength is known. The model uses one constraint for each wavelength where the curves are matched – a total of sixteen constraints. The K/S values of the target at each wavelength are calculated and entered in the tableau as the right hand side of that constraint. The alpha values of the selected dyes form the left hand sides of the constraints.

The simplex algorithm solved the problem or announced that no solution was possible. If no solution was possible the calculation was repeated with a different combination of dyes until a solution was found or all the dyes were tried.

Table 4: Slop and Correlated Values of N. Blue HER forDifferent Percentage of Shades

	0.1	0.3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SLOPE	CORRE
400	0.029	0.049	0.097	0.148	0.248	0.336	0.439	0.548	0.670	0.752	0.189	0.989
420	0.036	0.062	0.115	0.174	0.285	0.379	0.492	0.613	0.741	0.833	0.207	0.991
440	0.039	0.068	0.126	0.191	0.309	0.411	0.530	0.661	0.799	0.892	0.222	0.991
460	0.043	0.074	0.138	0.208	0.336	0.446	0.575	0.716	0.862	0.966	0.240	0.991
480	0.049	0.085	0.155	0.233	0.376	0.500	0.643	0.800	0.962	1.073	0.267	0.991
500	0.061	0.105	0.189	0.280	0.449	0.591	0.759	0.949	1.139	1.266	0.314	0.991
520	0.076	0.130	0.232	0.336	0.534	0.701	0.901	1.125	1.348	1.500	0.370	0.991
540	0.111	0.186	0.326	0.467	0.739	0.969	1.243	1.554	1.865	2.074	0.510	0.991
560	0.161	0.269	0.464	0.662	1.049	1.374	1.766	2.226	2.672	2.970	0.730	0.990
580	0.212	0.352	0.606	0.864	1.375	1.808	2.326	2.943	3.536	3.934	0.968	0.990
600	0.253	0.422	0.722	1.036	1.649	2.186	2.809	3.548	4.256	4.752	1.169	0.990
620	0.266	0.446	0.759	1.096	1.759	2.326	2.985	3.766	4.504	5.051	1.242	0.990
640	0.246	0.417	0.711	1.037	1.648	2.175	2.801	3.516	4.203	4.675	1.154	0.991
660	0.141	0.250	0.433	0.645	1.018	1.331	1.707	2.133	2.528	2.848	0.700	0.992
680	0.049	0.093	0.168	0.261	0.416	0.550	0.699	0.866	1.025	1.161	0.287	0.994
700	0.009	0.018	0.037	0.062	0.104	0.144	0.188	0.234	0.284	0.325	0.082	0.990

Input Data Preparation

The alpha or slope values of all the dyes (10 different dyes) were calculated from the K/S values (indirectly from the reflection data) of the respective dye. Then they are entered into the basic program as input data. Similarly the targets data and blank sample's data are determined and entered into the program which is given in the table 5.

After running the program, the result of the output file was printed and the different recipes were examined. Selecting the best (closest fit) recipe among the combinations, a dyeing was carried out. Then the reflectance data of the dyed samples was taken and compared with the targets reflectance data, the ΔE value of the target and the sample were calculated and graded using MS Excel.

Table 5: Alpha Values for Various Colour Dyed Fabric and Grey Fabric

	N.Blue HER	Blue HEGN	Yellow HE4R	Yellow HE4G	Red HE7B	Red HE3B	Torq. Blue H5G	Violet 5R	Orange HER	Black HN	*Blank (RFD Fabric)
400	0.259	0.113	0.367	0.994	0.209	0.140	0.062	0.025	1.447	0.713	0.062
420	0.301	0.087	0.436	0.731	0.195	0.133	0.029	0.016	1.250	0.779	0.049
440	0.311	0.094	0.482	0.497	0.186	0.146	0.015	0.019	1.285	0.783	0.04
460	0.314	0.119	0.448	0.275	0.257	0.224	0.008	0.034	1.572	0.863	0.034
480	0.342	0.156	0.368	0.122	0.490	0.384	0.008	0.054	2.037	1.045	0.03
500	0.418	0.203	0.263	0.039	0.835	0.603	0.011	0.091	2.228	1.174	0.027
520	0.516	0.258	0.136	0.004	1.247	0.780	0.021	0.148	2.049	1.140	0.025
540	0.707	0.320	0.046	0.000	1.286	0.771	0.054	0.198	0.961	0.958	0.024
560	0.966	0.415	0.010	0.000	1.339	0.624	0.131	0.222	0.204	0.793	0.023
580	1.226	0.551	0.002	0.000	0.574	0.203	0.232	0.215	0.033	0.801	0.022
600	1.482	0.688	0.001	0.000	0.103	0.036	0.364	0.111	0.004	0.868	0.021
620	1.629	0.737	0.000	0.000	0.014	0.005	0.440	0.041	0.000	0.832	0.02
640	1.539	0.734	0.000	0.000	0.001	0.001	0.468	0.021	0.000	0.611	0.019
660	0.951	0.561	0.000	0.000	0.000	0.000	0.689	0.013	0.000	0.316	0.017
680	0.381	0.321	0.000	0.000	0.000	0.000	0.832	0.008	0.000	0.139	0.016
700	0.105	0.153	0.000	0.001	0.000	0.000	0.322	0.004	0.000	0.048	0.015

* Absorption data of the grey fabric

Running the Program

In order to obtain the recipes for matching the Target, a software program was developed using the BASIC language. The flowchart is shown below explains the program logic (Figure 8).

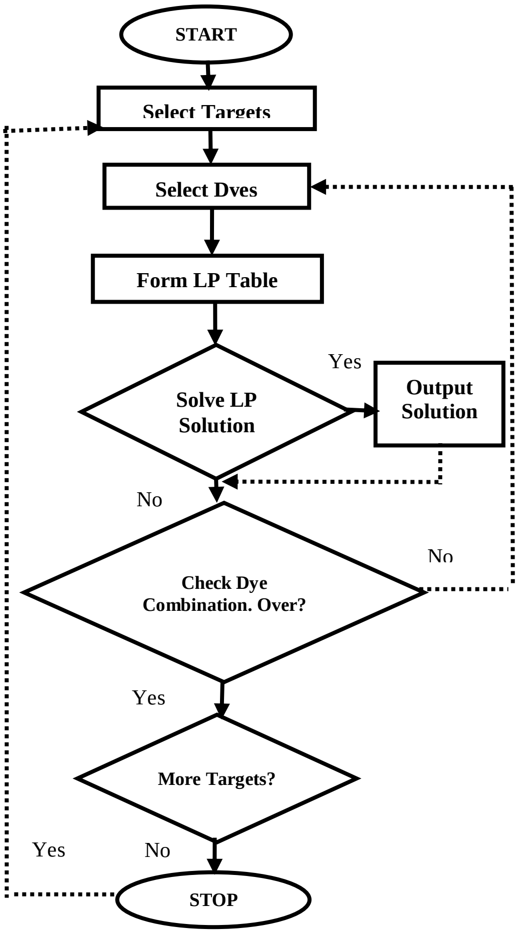

Figure 8: Flowchart Showing the Function of the Program

Once the input data is entered into the program, it selects the first target's data and compares it with the colourant data to match the spectral reflectance curve within the tolerance limit. This is done by solving a LP problem. If there is a solution, then it prints the output and checks for the next dye combination. If there is no solution, then it selects the next dye combination without printing the output. This loop is continued till all the dyes are over.

RESULTS AND DISCUSSION

The recipes that are determined by the program are dyed to match the target colour. About 10 targets were tried and out of that 7 targets able to match without any colour difference. The Δ E values are also less than 1. Their reflectance graphs were also plotted and seen that they move very close to the target throughout the visible region. The samples were also viewed and compared with the target. Under different lamps in the colour matching cabinet like TL84, D65, IncA, CWF etc. gives same colour change on both target and match. It indicates that there is no ‘metamerism’ between the target and the match. From the experiment, non-metameric colour matching was achieved for 7 samples for which ΔE value was less than 1. For remaining 3 samples, the dye chosen are not suitable to predict the precise colour recipe.

Matching the Target

In order to check out the program, a few synthetic target recipes (computed mixes) were prepared and entered into the program. The program gave recipe with the correct dyes and with the actual amount accurate to the second decimal place. So, it can be concluded that the program is working correctly. The program also suggested recipes with other dyes and amounts.

Some knitted targets were collected and tried as targets for the spectral curve colour matching process. These trials were a check of the possibility of matching, the targets having different fabric structure and dyed with an unknown dye mixture.

Predicted Recipe for Knitted Target 10 with Tolerance of 1%

Blue HER = 0.1423027

Yellow HE4G= 0.8097279

Red HE7B= 5.815639e-002

Black HN= 2.598464e-002

For matching the target 10, the recipe shown above is chosen for dyeing from the program predicted. The graph shown in the Figure 9 is obtained from the reflectance value predicted by the program.

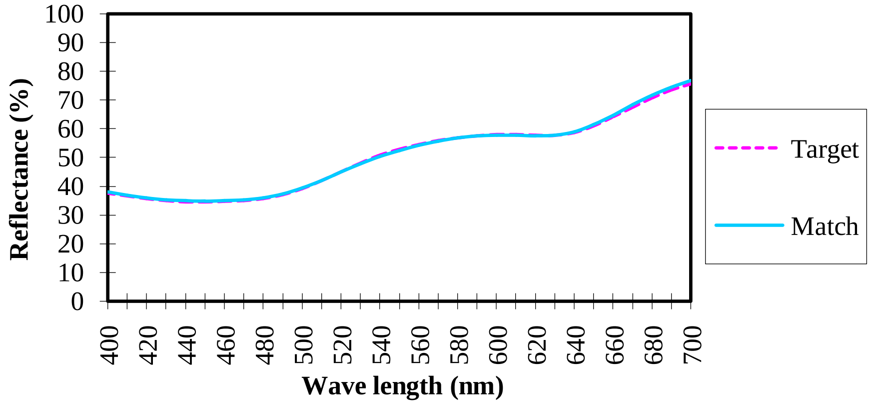

Figure 9: Reflectance Curves of the Target and Predicted Match

The outcome of this work of getting the spectral curve colour matching (reflectance match) for different fabric structure is largely positive. One sample of the output is discussed here. The graph for knitted target 10 and its matching closeness of the curves needs no further explanations. An example of matching a target using the predicted recipe is shown in the below diagram with different illuminants like D65, TL84, CWF, INC A and their combination with UVThe photographs of the target and the dyed matches under different illuminants are shown in Figure 10. The maximum Δ E is under the TL-84 illuminant but even here the colour difference value (Δ E) is found to be 0.61.

D-65 **D65+UV**

TL-84TL-84 + UV

CWF INC A

Figure 10:Photographs of Knitted Target and the Matching sample at different illuminants

CONCLUSION

Non-metameric colour matching system can avoid potentially embarrassing situations that may arise due to colour of an outfit (dress and accessories) not matching under different lighting conditions. From an industrial as well as a commercial point of view, it is often essential to achieve the smallest possible 'ΔE' value. So, when it becomes possible to match the reflectance curve of the target sample, giving a non-metameric match or a match with a low metameric value, it may be the preferred method of match in many cases.

This method described can give a way to achieve a non-metameric colour. Even if the dyes used on the target are unknown, it is sometimes possible to match the reflectance curve within that tolerance limit where the human eye cannot distinguish the colour difference.

This method was developed not to replace the conventional CIE system of colour matching, but as an addition.This method is independent of parameters like the standard observer data or spectral power distribution curve of different illuminants. It is therefore likely that solutions by this method are immune to 'Illuminant Metamerism' as well as 'Observer Metamerism'.

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