The effect of humidity, fabric surface geometry and dye type on the colour of cotton fabrics dyed with a select range of anionic dyes

M. Senthilkumar [a], N. Selvakumar [b], R. Shamey [c],*

[a] Department of Textile Technology, PSG College of Technology, Coimbatore 641004, India
[b] Department of Textile Technology, Anna University, Chennai 600025, India
[c] Department of Textile Engineering, Chemistry and Science, North Carolina State University, College of Textiles TECS, 2401 Research Drive, Raleigh 27695-8301, USA

ABSTRACT

Twill and plain woven bleached cotton fabrics were dyed with a trichromatic set of dyes, C.I. Direct Red 243, C.I. Direct Yellow 106, C.I. Direct Blue 85 individually, with different combinations of these dyes and also with C.I. Reactive Red 24. Dyed fabrics were subsequently conditioned at 0, 25, 45, 65 and 85% relative humidity levels to study the effect of various atmospheric humidity levels, expressed by moisture content, on the colour of substrates. A mass balance was performed and dye uptake by the fabric was normalized based on the mass and size of the substrate to minimise error when determining the effect of moisture and fabric surface geometry on colour. Variations in colour between conditioned samples were assessed using two methods: the ΔE^*_{cmc} colour difference equation and the summative Kubelka–Munk function. For the same amount of dye present on fabrics, due to increased effective surface area, twill structures exhibited higher increases in their depth of colour than plain woven substrates for any of the relative humidity levels examined. The findings reveal that the moisture absorbed by the fabric from the environment, and fabric geometry, significantly affect fabrics apparent colour and the effect is more pronounced at higher humidity levels.

Published by Elsevier Ltd.

1. Introduction

Surface colour measurement and colour matching are of great importance for a wide range of coloured goods and various industries. Care in colour matching has to be exercised to limit overall production costs while satisfying a stringent set of quality measures. The stimuli perceived as colour is the result of a complex interaction of incident light with an object, determined by the optical characteristics of the object, and the human visual system. Such interactions not only depend on the amount of colorant present but are also influenced by other foreign matters such as moisture, and chemical additives present within the medium. In the case of textile materials, the moisture content varies in conjunction with the atmospheric humidity. This in turn leads to variations in the interaction of light with the substrate, which affects its colour.

When light falls on a textile material scattering takes place at the surface. The extent of scattering depends on the surface characteristics of the material. Some of the light, however, diffuses into the

medium and is subsequently absorbed or scattered internally [1,2]. Internal scattering of light within textile materials depends on a number of factors which include the concentration of dye/coloured molecules, as well as the presence of foreign constituents such as water or chemical compounds. In addition, the transformation of dyed textile substrates from the dry to wet state results in a reduction in total reflectance due to reduced light scattering [3]. Allen and Goldfinger [4] noted that a decrease in scattering efficiency would provide an opportunity for the increased absorption of light. The earlier research reports indicate that changes in reflectance properties of a fabric, due to the influence of moisture, are physically attributable to changes in its surface properties [5,6].

In practice the moisture content of a substrate may fluctuate due to variations in the relative humidity of the surrounding environment. Such variations influence the interaction of light with the substrate and its colour [7,8]. Inadequate assessment of the role of relative humidity on the colour of substrates can complicate colour communication throughout the supply chain and adversely affect the (re)production of colour. The geometry of the reflecting surface also directly influences the amount of scattered light which in textiles can vary widely. Recently a potential model was reported which included the effect of fabric structure on the predicted colour of textile substrates [9]. The influence of relative humidity (RH) and

Table 1
Fabric specifications.

Parameters	Fabric Type			
	T1	T2	P1	P2
Warp yarn Count/Ne	24	24	24	24
Weft yarn Count/Ne	20	20	20	20
Ends/inch	74	74	74	74
Picks/inch	72	60	52	40
Warp yarn diameter/mm	0.185	0.185	0.185	0.185
Weft yarn diameter/mm	0.203	0.203	0.203	0.203
End spacing/mm	0.343	0.343	0.343	0.343
Pick spacing/mm	0.353	0.423	0.488	0.635
Warp crimp/%	4.8	4.9	5.1	4.8
Weft crimp/%	7.1	6.9	7.0	6.9
g/m^2	181	153	140	113

surface geometry on the colour of textile substrates, however, needs to be clearly elucidated and this merits further investigation. In this study an attempt was made to determine how the change in colour of the dyed substrate is influenced by variations in the RH.

The amount of dye on fabric can be predicted using the well-known Kubelka–Munk model [10], shown in Equation (1).

$$K/S = \frac{(1 - R_\infty)^2}{2R_\infty} \tag{1}$$

where K and S represent absorption and scattering coefficients respectively, and R_∞ denotes reflectance factor from an opaque object. Many approaches to modelling reflectance of opaque and translucent materials have been attempted which include modifications to the Kubleka–Munk model [11–19]. In the case of opaque and light absorbing/scattering materials, single-constant Kubelka–Munk theory is used to describe the complex-subtractive colour mixing in the medium. However, the theory does not take into account the surface scattering phenomena and therefore surface correction must be carried out to improve the accuracy of predictions. While myriad research has been conducted in modelling light reflectance from fabric surfaces over the last 40 years, a very limited amount of work has been reported on the development of a colour prediction model that includes variables such as fabric surface geometry, moisture content as well as dye type and concentration and opportunities for further work exist for researchers in the field. The study reported here examines the effect of humid conditions, determined by the moisture content of the substrate, and fabric geometry on the colour of cotton fabrics dyed with three direct dyes as well as one reactive dye. The results can be used to develop new colour prediction models or improve the performance of the existing systems.

2. Materials

In order to determine the effect of fabric surface characteristics on the colour of the substrate two different woven structures namely plain (P) and twill (T) were examined. In both structures pick density was varied to obtain different levels of effective surface area. Specifications of fabrics used are given in Table 1.
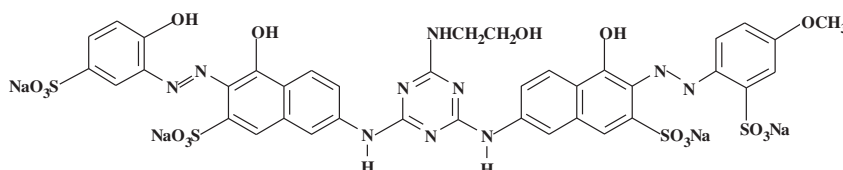
Three commercial grade Direct dyes namely C.I. Direct Red 243 (R), C.I. Direct Yellow 106 (Y), C.I. Direct Blue 85 (B) and one commercial grade Reactive dye namely C.I. Reactive Red 24 (RR) supplied by DyStar, USA as well as laboratory grade sodium chloride (NaCl) and sodium carbonate (Na$_2$CO$_3$) were used as received for dyeing. The structures of dyes used for this study are given in Figs. 1–4.

3. Experimental procedure

3.1. Preparation of dyed samples

Direct Dyes were applied individually and as a mixture in different proportions to dye the fabric samples as shown in Table 2. The bleached unmercerised cotton fabric samples were dyed at 0.5, 2.0, 3.5 and 5.0% depth of shade based on mass of fabric (omf) in presence of 5, 10, 15 and 20 gL^{-1} NaCl respectively. The material was introduced to a bath containing the required quantity of dye and 0.1 gL^{-1} Na$_2$CO$_3$ at 50 °C. Liquor to goods ratio was set at 40:1. Temperature of the bath was gradually raised to 90 °C and the dyeing was continued for 30 min. Electrolyte additions were made in three steps at 5th, 10th and 15th min during dyeing.

In the case of reactive dye the bleached samples were also dyed at 0.5, 2.0, 3.5 and 5.0% depth of shade based on mass of fabric (omf) in presence of 10, 15, 20 and 25 gL^{-1} NaCl respectively and 20 gL^{-1} Na$_2$CO$_3$. The sample was introduced in a bath containing the dye and the temperature was gradually raised to 90 °C and the dyeing was continued for 30 min. Electrolyte additions were made at 5th, 10th and 15th min after the bath reached 90 °C. The required amount of alkali was then added and dyeing was continued for another 30 min to fix the dye.

Immediately after completion of dyeing i.e., before washing, a small piece of fabric was cut from the dyed sample and its reflectance was measured. The remaining portion of dyed samples were washed using cold water for 5 min followed by wash-off with a non-ionic detergent (2 ml L^{-1}) at 30 °C for 5 min and finally the samples were thoroughly washed with running tap water until clear. After drying, the samples were checked for the presence of unfixed surface deposited dye molecules by means of washing. To ensure the repeatability of results triplicate samples under every set of conditions were produced.

3.2. Determination of dye uptake

The absorbance of blank solution containing all auxiliaries except dye (A_1) and the solution after dyeing (A_2) at their respective λ_{max}, shown in Table 2, was measured using a UV–Visible spectrophotometer (Cary 3E, USA). The percentage exhaustion (%E) of dye solution was calculated using Equation (2).

$$\%E = \left[1 - \frac{A_2}{A_1}\right] \times 100 \tag{2}$$

The reflectance value of dyed samples immediately after removal from dyebath and also after washing was measured separately in the range of 400–700 nm at an interval of 10 nm using a DataColor SF600X spectrophotometer. UV light was excluded and specular

Fig. 1. C.I. Direct Red 243 (R).