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Batchwise dyeing of bamboo cellulose fabric with reactive dye using ultrasonic energy

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ABSTRACT

Bamboo is a regenerated cellulose fiber usually dyed with reactive dyes. This paper presents results of the batchwise dyeing of bamboo fabric with reactive dyes by ultrasonic (US) and conventional (CN) dyeing methods. The study was focused at comparing the two methods for dyeing results, chemicals, temperature and time, and effluent quality. Two widely used dyes, CI Reactive Black 5 (*bis*-sulphatoethylsulphone) and CI Reactive Red 147 (difluorochloropyrimidine) were used in the study. The US dyeing method produced around 5–6% higher color yield (K/S) in comparison to the CN dyeing method. A significant savings in terms of fixation temperature (10 °C) and time (15 min), and amounts of salt (10 g/L) and alkali (0.5–1% on mass of fiber) was realized. Moreover, the dyeing effluent showed considerable reductions in the total dissolved solids content (minimum around 29%) and in the chemical oxygen demand (minimum around 13%) for the US dyebath in comparison to the CN dyebath. The analysis of colorfastness tests demonstrated similar results by US and CN dyeing methods. A microscopic examination on the field emission scanning electron microscope revealed that the US energy did not alter the surface morphology of the bamboo fibers. It was concluded that the US dyeing of bamboo fabric produces better dyeing results and is a more economical and environmentally sustainable method as compared to CN dyeing method.

1. Introduction

Recent environment conservation regulations have given considerable importance to the renewable natural materials. Bamboo is a renewable natural resource of cellulose nature and it originates from grass family [1,2]. The bamboo fiber is regenerated from the bamboo grass. It is lighter in weight, and has soft and smooth handle [3] and excellent wicking properties [3,4]. This is mainly due to its high porosity [5]. The porosity also contributes towards its cooler feel. It is also claimed to be more sustainable than most of the textile fibers [6]. Because of its many unique properties, bamboo fiber has gained attention towards its use for textiles specially apparels [7]. Due to high fiber porosity, the bamboo textiles produce higher color yields when dyed. The environmental issues related to dyeing textiles such as the polluted effluent discharge have gained prime attention by the dyeing industry for quite some time [8]. However, the prime concerns such as reducing processing costs, improving quality, and faster delivery are still on priority [8,9].

In batchwise textile dyeing, the substrate remains in contact with the dye liquor and the fiber absorbs the dye molecules [10]. The dye concentration in the dyebath gradually decreases with a simultaneous build-up of the dyes on the fiber surface [11]. Temperature plays an important role in achieving dye diffusion and uniform dye migration inside the fiber polymer system. Dye fixation, when dyeing cellulose textiles with reactive dyes, starts as the pH of dyebath is increased by the addition of an alkali [12].

Ultrasonic (US) energy is broadly divided into power ultrasound (20 kHz–2 MHz) and diagnostic ultrasound (5–10 MHz) [13]. The power ultrasound produces acoustic cavitation in liquids and can accelerate a wide variety of physical and chemical reactions due to cavitation [14]. Because, cavitation is the growth and implosive collapse of microscopic bubbles capable of producing hot spots [15]. The prime benefit of using US energy in textile dyeing is improvement in mass transfer which can otherwise be achieved through high temperature, prolonged time and addition of various chemicals [10]. The ultrasound assisted dyeing for textiles is widely reported in terms of energy savings and environmental benefits. It includes dyeing cotton with reactive dyes [8], cationic cotton with natural dye [16], wool with natural dye [17], nylon with reactive dye [9], acrylic with basic dye [14] and cellulose acetate with disperse dye [10]. As the dyeing characteristics of bamboo fabrics are better than other

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cellulose fabrics, it was expected to have more promising results by US dyeing of bamboo fabric. Herein, we present the batchwise dyeing of bamboo fabric with reactive dyes using power ultrasound and provide comparative study versus conventional (CN) dyeing method. Factors affecting dyeability and colorfastness properties were thoroughly investigated. Total dissolved solids (TDS) contents and chemical oxygen demand (COD) of the representative effluents of US and CN dyeings were also tested. The morphology of dyed fabrics was further observed on a Field Emission Scanning Electron Microscopy (FE-SEM).

2. Experimental

2.1. Materials

A single jersey knitted bamboo fabric (mass: 40 g/m^2) was used. Two reactive dyes, namely CI Reactive Black 5 (*bis*-sulphatoethylsulphone based, DyStar Pakistan Private Limited) and CI Reactive Red 147, (difluorochloropyrimidine based, Archroma Pakistan Limited) were selected on account of their commercial usage, variety of reactive groups and colors. Sodium chloride, sodium carbonate and 50% sodium hydroxide were of analytical grade. Ladipur RSK (anionic detergent based on polycarboxylic acid, Archroma Pakistan Limited) was of commercial grade. Distilled water was used for all the experiments done in this study.

2.2. Apparatus and setup

The CN batchwise dyeing of bamboo fabrics was carried out on an HT dyeing machine (Rapid Labortex H-120, Taiwan). The US dyeing was performed on an US bath (Getidy KDC-200B, China) of 5 L capacity. In order to achieve necessary agitation during US dyeing process, the equipment was setup locally by putting it over an electric agitator plate. The power input and the US frequency were set to 300 W and 40 kHz, respectively. For US dyeings, the dyebath was prepared in a conical flask and dipped into the US bath already filled with water. A local setup was prepared to hold the flasks dipped into the US bath during a dyeing process. Cold water was manually circulated inside the US bath to maintain the dyebath temperature whenever required.

2.3. Methods

2.3.1. CN batchwise dyeing of bamboo fabric

The bamboo fabric samples were dyed by preparing the dyebath with 2% reactive dye (o.m.f) and liquor ratio of 15:1. For dye exhaustion, sodium chloride (50 g/L for CI Reactive Black 5 and 60 g/L for CI Reactive Red 147) was added to dyebath at 40 °C and treated for 60 min, followed by adding sodium carbonate (5% o.m.f for CI Reactive Black 5 and 2.5% o.m.f for CI Reactive Red 147) then raising the dyebath temperature to 60 °C. The dyeing was continued for 60 min for ensuring the dye fixation. For CI Reactive Black 5, 1.5 ml/L of sodium hydroxide (50%) was also added for dye fixation. The quantities of sodium chloride, sodium carbonate and sodium hydroxide were as per dye manufacturers' recommendations. The washing-off process of the dyed samples was carried out by batchwise method (cold rinse → warm rinse → soaping-off → warm rinse → cold rinse). The soaping-off was done at boil for 15 min, with 2 ml/L Ladipur RSK and 50:1 liquor ratio, until the color bleeding stopped.

2.3.2. US dyeing of bamboo fabric

The US dyeing and washing-off were carried out in exactly same manner as the CN dyeing described in previous section. The equipment setup was different as described in Section 2.2.

2.4. Color measurement and testing

Reflectance values of each dyed sample were measured on a Datacolor SF600 spectrophotometer using the following instrument settings (8.4 mm sample aperture, illuminant D65, UV and specular component included). Each sample was measured at five different locations and the average value was reported. Using the reflectance value at maximum absorption, the color yield (K/S) was calculated with the Kubelka–Munk equation (Eq. (1)) [18].

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

where R is reflectance value of the dyed fabric at maximum absorption, K is absorption coefficient and S is scattering coefficient.The percentage of reactive dye fixed on bamboo fabric was measured using the following equation.

$$\%F = \frac{(\frac{K}{S})a}{(\frac{K}{S})b} \tag{2}$$

where F is dye fixation, $(K/S)_a$ is color yield after wash and $(K/S)_b$ is color yield before wash.

Colorfastness to washing (ISO 105-C03) test was performed on a Gyrowash (James H. Heal Co., UK), colorfastness to light (ISO 105-B02) test was carried out on an Apollo (James H. Heal Co., UK) and colorfastness to rubbing (ISO 105-X12) was done on a Crockmeter (James H. Heal Co., UK).

2.5. Effluent testing

Of each optimum dyeing, left over dyebath and washing-off wastewater were mixed together for effluent testing. For this purpose, fabric sample of 8 g was dyed and each washing-off step was carried out in constant amount (400 ml) of distilled water. The effluents were assessed for TDS contents with digital TDS meter (Oakton, USA) and COD value (HACH method).

2.6. Bamboo fabric morphology

The morphology of dyed bamboo fabrics were comparatively examined on a Field Emission Scanning Electron Microscope (FE-SEM; JSM 6701F, JEOL Japan) at a magnification of 2000× using 15 kV accelerating voltage. The fabrics were coated with Platinum under vacuum by sputtering method.

3. Results and discussion

3.1. Dyeing of bamboo fabric by CN method

Fig. 1(A–D) outlines the effect of different parameters on K/S and $\%F$ of bamboo fabric dyed with CI Reactive Black 5 by CN method. It can be seen that the K/S and $\%F$ increase with increasing sodium chloride concentration (0–60 g/L). This may possibly be due to the fact that sodium chloride, acting as an electrolyte, promotes dye diffusion and ultimately K/S and $\%F$ [19]. However, a decrease in K/S and $\%F$ was observed at 60 g/L sodium chloride concentration. This suggests that there is an increase in the degree of aggregation of dye molecules [20] on the fiber surface retarding the dye diffusion inside the fiber polymer system. Similar trend of results was observed for sodium carbonate concentration, with constant sodium chloride (50 g/L). 5% was the optimum sodium carbonate concentration found for CI Reactive Black 5, and no further enhancement in K/S and $\%F$ was obtained at 6% sodium carbonate concentration with constant sodium hydroxide concentration. This may be due to the excess in dyebath pH increased the dye hydrolysis [19]. The K/S and $\%F$ increased