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The effect of tris(2-carboxyethyl)phosphine on the dyeing of wool fabrics with natural dyes

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ABSTRACT

The influence of the introduction of tris(2-carboxyethyl)phosphine on the dyeing of wool with natural dyes was studied and the kinetics and thermodynamics of the dyeing process were also investigated. None of the previous techniques employed report the possibility of modification of wool fibers with tris(2-carboxyethyl)phosphine for dyeing. The modified wool fabrics represented important advances in dye adsorption and decrease in dye desorption at a low dyeing temperature (80 °C) that are not available in the other systems without metallic mordants. Our results demonstrated that the adsorption of natural dyes on wool fabrics was greatly improved through the selective reduction of disulphide bonds with tris(2-carboxyethyl)phosphine. In addition, experiment data was analyzed using pseudo-second order kinetics and Langmuir type isotherms. The results indicated that the diffusion coefficient of dyes was increased while the dyeing entropy and enthalpy were decreased with the introduction of tris(2-carboxyethyl)phosphine.

1. Introduction

Wool, which exhibits the characteristics of feeling soft, heat retention and comfortable to wear, is amongst the earliest natural fibers for textiles and very important for human being to live in the eco-friendly world. Due to this, eco-friendly processing of wool (pre-treatment, dyeing and after-finishing) is critical to the added-value of the resulting materials. Natural dyes are believed to be suitable for the coloration of wool fabrics, because of their generally low toxicity, reduced pollution and biodegradable nature [1–4]. Recently, most researchers have focused on the studies of plant and microorganism-pigments, such as chlorophyll [5], laccaic acid [6], tea pigment [7], prodigiosin [8], rumexmadaio [9], curcumin and brazilin [10], gardenia [11]. Among these, the gardenia has attracted most attentions due to their simple extraction, strong acceleration and good compatibility with other ions, and is believed to be the most promising natural dye for dyeing of wool fibers (the structure is shown in Fig. 1) [12].

Unfortunately, the broad development of natural dyes in dyeing is thwarted by the high molecular mass, which disfavors their penetration into the inner wool fiber, resulting in the decrease adsorption of dyes on the fibers and increase desorption of dyes from the fibers. Nowadays, dyeing mordants have been used to improve dye adsorption on wool fiber and its dyeing fastness. Ferrous sulfate, aluminum sulfate and potassium sodium tartrate have been introduced in the dyeing of wool with chlorophyll and carminum, resulting in the significant improvement of coloration and fastness [5]. Burkinshaw et al., studied the effect of the presence of tannic acid and $FeSO_4$ on the dyeing of wool with C. I. mordant black 8. The results showed that the dye/(tannic acid + $FeSO_4$) systems yielded superior dyeing fastness compared with other dyeing systems [13]. However, due to the lack of an ideal accelerating effect, the resulting dyed fibers based on these mordants have coloration and dyeing fastness that fall far below the expected theoretical values of the resulting fibers. In addition, most mordants used in the dyeing of wool contain metal ions, which affect the coloration of the dyed wool fibers, and are harmful to the environment. Thus, there is a critical need for designing and establishing eco-friendly mordants, which are effective on the dyeing of wool fibers.

Tris(2-carboxyethyl)phosphine (TCEP) is a thiol-reducing agent, which has strong selective reduction for disulfide bonding in proteins [14]. With the introduction of TCEP, the disulfide bonding can be opened, and meanwhile TCEP is oxidized to TCEP oxide. The toxicities of TCEP and TCEP oxide were evaluated using rat hepatocyte and human neuron as models [15,16]. It was proved that both TCEP and TCEP oxide are low in toxicity and environmentally friendly. Thus, TCEP was used in this

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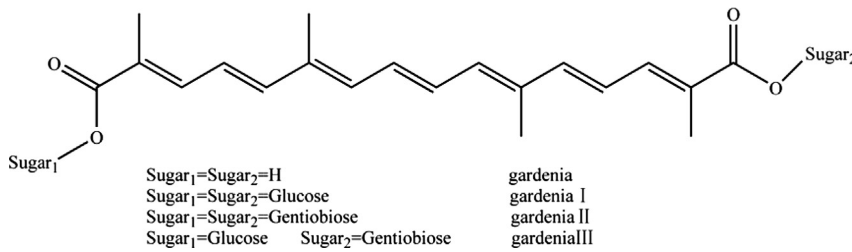

Fig. 1. The chemical structure of mainly components of gardenia.

research. In our work, the effect of the introduction of TCEP on the dyeing of wool fabrics with gardenia yellow at low temperature was studied and the accelerating mechanism of TCEP was also explored. Furthermore, the kinetics and thermodynamics of dyeing process were investigated.

2. Experiment section

2.1. Materials

Wool fabrics with diameter of 19.88 μm were purchased from Zhejiang Xinao Textiles Inc., TCEP were purchased from Tianjin Liankuan Fine Chemicals Co., Ltd, Tianjin, China and Gardenia yellow was obtained from Qianjiang Green Sea Treasury Biotechnology Co., Ltd, Guangdong, China. The Gardenia yellow was extracted with alcohol (content and temperature ~50% and 50 °C, respectively) three times before use. All chemicals used in our work were of laboratory grade.

2.2. Dyeing of wool

Dyeing of wool fabrics was carried out in a dyeing machine (HWX-23, Zhenhe Chemical Instruments Co., Ltd, Zhejiang, China) equipped with timer and temperature controller. A pH meter (FE20-FiveEasy, Mettler-Toledo International Inc.) was used to measure the pH values of the dyeing solutions. The dyeing was carried out using different concentrations (o.w.f%) of gardenia yellow and 0.3% of TCEP, at a material to liquor ratio of 1:1000 and maintaining at a pH value of 4 and temperatures at 80 or 90 °C, respectively.

2.3. Fastness and color testing

The color fastness of the samples to washing and rubbing (wet and dry) was determined using the ISO 105: CO6 2010 and ISO 105: X12 2001test methods, respectively. K/S value of dyed samples was calculated from the reflectance at the wavelength of 450 nm using a spectrophotometer (X-Rite, Gretag Macbeth Colour-Eye 7000A) with UV component included and specular component excluded [17].

2.4. Dyeing kinetics

The dyeing kinetics were studied through the adjusting the dyeing time of wool (5 min, 10 min, 20 min, 30 min, 40 min, 50 min, 60 min, 70 min, 80 min, 100 min, 150 min and 200 min). The liquor ratio was 1:1000. The amount of dyes remaining in the solutions was detected by measuring the absorbance of the solutions using a UV–Vis spectrophotometer (721, Jinghua Scientific Instruments Co., Ltd, Shanghai, China). The absorbance of the solutions was measured and Eq. (1) was used to calculate the amount of dye adsorbed at equilibrium (q_t, mg/g):

$$q_t = 4\% \times \left(1 - \frac{A_t}{A_0}\right) \times 100\% \times 10^3 \tag{1}$$

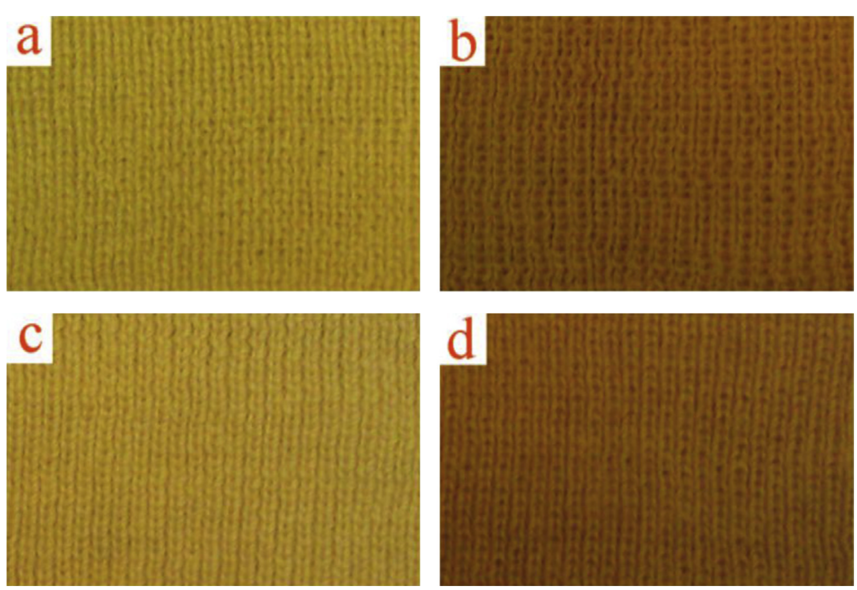

Fig. 2. Various colors of knitted wool fabrics dyed with gardenia yellow. (a) 80 °C without TCEP, (b) 80 °C with TCEP, (c) 90 °C without TCEP, (d) 90 °C with TCEP.