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Silicone nanomicelle dyeing using the nanoemulsion containing highly dispersed dyes for polyester fabrics

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ABSTRACT

Silicone nanomicelle dyeing is a novel dyeing technique of saving water and energy. The organic silicone nanomicelles containing highly dispersed dyes were prepared. Organic silicone oil as a polymer organic phase was successfully used as nanoemulsion by solvent evaporation technique. Three nanomicelles containing three dyes are all homogeneous liquid nanospheres with regular shape and size 40–60 nm, respectively. The dyes were highly dispersed in the nanoemulsion in molecules. Dyeing for PET fabrics can be carried out in low liquor ratio. The dye was slowly released from the nanomicelle in the dyeing process and improved the leveling property of the disperse dyes. The color yields of the polyester fabrics dyed by the nanomicelle dyeing were higher than those of the samples dyed by the traditional dyeing. During the dyeing process, the organic silicon was also as softening agent, which adsorbed on the surface of the fabric to provide a good soft handle. This technique combined dyeing and finishing processes together. The nanomicelle dyeing improved the dyeing properties of polyester fabrics and to save time and reduce the water consumption.

1. Introduction

Polyethylene terephthalate fibers (PET) possess excellent wearability, such as comfort, soft, good cost performance et al. (Ren et al., 2017; Kaynak and Babaarslan, 2016; Rajan et al., 2016; Sun et al., 2016). High temperature and high pressure dyeing in the water bath with disperse dyes is the main dyeing method for PET fabrics. In order to improve the leveling performance, large bath ratio (1:15–20) is often applied in the conventional dyeing process. In general, commercial disperse dyes also contain a large number of dispersants, which cannot be dyed onto the fibers. So, PET dyeing process consumes a lot of water, energy and chemicals. A lot of dyeing wastewater containing auxiliary chemicals and residual disperse dyes is discharged to pollute the environment. (Ferrero and Periolatto, 2012). Therefore, water and energy saving, and pollution reduction to achieve cleaner production are the main investigating directions in printing and dyeing fields. (Alkaya and Demirer, 2014; Xu et al., 2016).

In the recent years, many efforts have been made to investigate the new cleaner production dyeing techniques. One of more active fields is water free dyeing, which include supercritical carbon dioxide (SCD) dyeing (Long et al., 2014; Zhang et al., 2016; Huang et al., 2017) and organic solvent dyeing technology (Xu et al., 2016; Ferrero et al., 2011). However, those dyeing methods have its strengths and limits (Xu et al., 2016). One of the limitations of SCD dyeing is the high pressure requirement in the dyeing process. The high pressure equipment is expensive and consumes a lot of energy (Huang et al., 2017; Bach et al., 2002). Another water free dyeing method is solvent dyeing. Solvent dyeing does not require the use auxiliary chemicals (Xu et al., 2016). However, this method requires solvent recovery and reuse. These water free methods have not been applied in the practice production for various reasons.

Recently, nano-techniques are gaining attention in many fields, such as cleaner production, materials and biotechnology (Sundhoro et al., 2017; Krivec et al., 2017; Lawes et al., 2017). For polyester dyeing with disperse dyes, less water cleaner dyeing without additives is always the best and desired goal for researchers. The key technology to be solved is dye nano-dispersion in the dyeing process (Wang et al., 2016, 2017; Pransilp et al., 2016). Nanotechnology of the organic silicon nanomicelle containing dissolving disperse dyes offers the possibility. The silicon nanomicelle technique did not need to be dispersed by milling method, which did not require consume a large amount of energy.

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In this paper, the silicon nanomicelle containing highly dispersed dyes was investigated. The silicon nanomicelle dyeing was developed. The dyes were dissolved in organic silicone oil as polymer organic phase. Then the organic phase was dispersed in water and form silicone nanomicelle. The color nanomicelles containing dispersive dye were characterized by the particle size, polymer disperse index (PDI) and Zeta potential, transmission electron microscopy (TEM) analysis. The nanomicelle dyeing performance in low liquor ratio for PET fabrics were discussed.

2. Experimental

2.1. Materials

The pretreated PET fabric (100 denier) was obtained from Shaoxing Jinqiu Textile Company, Shaoxing, China. Amino modified silicon oil TY-938, which used as a softener in the finishing process, was obtained from Anhui Keguang New Material Company, Anqing, China. Emulsifier XL-70 was provided by BASF China, Shanghai, China. Three disperse dyes, D-O, D-R and D-B, and ethyl acetate (EtAc) were obtained from Zhejiang Wanfeng Chemical Company, Shaoxing, China. The dyes were not further purified before use. Sodium hydrogen carbonate and the other chemicals were obtained from Shanghai Chemical Reagent Plant, Shanghai, China.

2.2. Preparation of color nanomicelles

A certain amount of disperse dye was firstly dissolved in ethyl acetate (EtAc). The dye ethyl acetate solution was a color transparent solution and then slowly added to a certain amount of amino silicone TY-938 under stirring. Emulsifier XL-70, 8%, and distilled water were added into the dye ethyl acetate solution and mixed with high-speed emulsifier (4500 r/min) for 45 min to get subtransparent microemulsion. Acetic acid, 0.8%, was dripped into the system to adjust pH value. Finally, the EtAc was eliminated by evaporation under reduced pressure using a rotary evaporator with a vacuum pump RE-301 (Yuhua Instrument Co. Ltd, China) and the silicon nanomicelles containing highly dispersed dyes were obtained.

2.3. Dyeing of PET fabric with the nanomicelles

The nanomicelle dyeing for PET fabrics was carried out according to the described method (Li et al., 2015). The dyeing liquor ratio was set as 1:8. The pH value of the dyeing system was adjusted to 4.5. After dyeing, the samples were washed by reducing agent for 15 min at 85 °C. The reducing solution consisted of 0.5 g/l sodium hydrosulfite and 1.0 g/l sodium carbonate solution. The bath ratio was 1: 20. Then, all the samples were rinsed with water until the neutral. Dyeing samples were dried.

2.4. Dyeing of PET fabric with the traditional method

The PET fabric was dyed in a STARLET DL-6000 IR dyeing machine (Dealim Starlet Co., Ltd, South Korea) with a liquor ratio of 1:15 and level dyeing agent AS-1 1 g/L. The pH value of the dyeing solution was adjusted to 4.5. The fabric was immersed in the dye bath and increased to 130 °C at a rate of 2 °C/min. The dyeing process would last 60 min at 130 °C. After dyeing, the sample was washed in same way. At last, the fabric was dried.

2.5. Color yields and dye exhaustion (E%) of the dyed fabrics

The color yield (K/S) of the samples was measured by Datacolor SP600 + spectrophotometer, Datacolor Co., USA. The dyeing residue absorbance of the diluted with N,N-dimethylformamide (DMF) was measured. The dye exhaustion (E%) was calculated according to the following Eq. (1).

$$E(\%) = [1 - (A_1 \times N_1)/(A_0 \times N_0)] \times 100\% \quad (1)$$

where A_0 and A_1 are the absorbance of the dyeing solution at λ_{max} before and after dyeing, respectively; N_1 and N_0 are corresponding dilution ratio, respectively.

Color fastness was also evaluated according to ISO 105-E04 (2013) for fastness to perspiration, ISO 105-C04 (2010) for fastness to washing, ISO 105-X12 (2001) for fastness to rubbing. The handle of the samples was tested according to ASTM D1388 -96 (2002) test method.

2.6. Measurements

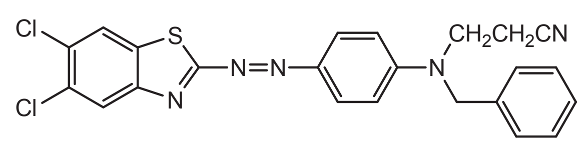
UV–Vis spectrum was measured by U-3310, UV–Vis spectrometer (HITACHI Cor., Japan). Laser Particle Size Analyzer, LS-13320 (Beckman Coulter, Inc., Brea, USA) was applied to measure the nanomicelle's particle size, polymer disperse index (PDI) and Zeta potential. TEM photographs were obtained with a JEM-2100 electron microscope (JEOL Cor., Japan).

3. Results and discussion

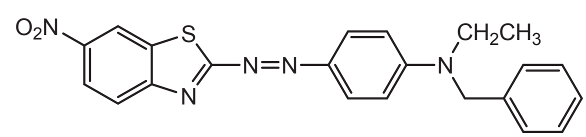
3.1. Preparation of the nanomicelle containing highly dispersed dyes

Three disperse dyes were applied for the preparation of color nanomicelles. The dyes are the most common dyes for the dyeing of PET fabric, which have red, blue and orange hue. Their chemical structures are shown in Scheme 1. The maximum absorption wavelengths of dye D-R, D-B and D-O were 535 nm, 622 nm, and 451 nm, respectively, corresponding to red, blue and orange hue.

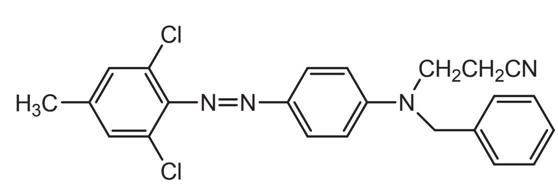
The disperse dyes can dissolve well in ethyl acetate to form the good transparent solution. Three disperse dyes were firstly dissolved in EtAc, respectively. The dye ethyl acetate solution was



D-R



D-B



D-O

Scheme 1. Chemical structures of three disperse dyes.