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Optimization of dye incorporation into modified poly(ethylene terephthalate) knitted fabrics by response surface methodology

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Abstract

Poly(ethylene terephthalate) can be modified by UV light and/or *N*,*N*-dimethylacrylamide to better incorporate disperse dyes. In this work, PET knitted fabrics were modified by DMAAm and UV light and then dyed with azo and anthraquinone disperse dyes. Factorial designs were performed at two levels using the following factors: DMAAm treatment time, dyeing time, and UV light exposure time. The best dyeing conditions were obtained with anthraquinone dye in the dyeing of UV light → DMAAm-modified PET knitted fabrics. In this case, the highest amount of incorporated dye was 6.3 mg/g under the following conditions: 77 min UV light exposure time; 15 min and 85 °C DMAAm treatment time and temperature, and 164 min and 85 °C dyeing time and temperature. The diffusion coefficients obtained were in the order of 10^{-5} cm^2/min. The results showed that the azo dye diffuses faster into modified PET than the anthraquinone dye does.

Keywords: Poly(ethylene) terephtalate; Disperse dye; UV light; *N*,*N*-Dimethylacrylamide; Response surface methodology; Dyeing

1. Introduction

Dyeing technology is based on physico-chemical equilibrium processes namely, diffusion and sorption of dye molecules and ions. Poly(ethylene terephthalate) (PET) fibers are the most important synthetic textile fibers in the world due to their high demand [1]. PET dyeing by disperse dye process comprises four stages [2]: (i) dissolution of dye molecules, which change from dispersed to dissolved state, (ii) molecule transport towards the fiber through the solution, (iii) transport by diffusion through the hydrodynamic boundary layer and immediate adsorption onto the fiber surface, and (iv) diffusion into the fiber. Because of the strong dyeing bath stirring in industrial processes, diffusion into the fiber is usually considered the process-determining step. For this reason, on studying the kinetics of PET dyeing, many researchers focus on the determination of the dye diffusion coefficient (D) into the polymer [3–5]. Moreover, due to the hydrophobic nature and the compact molecular structure [6,7] of PET fibers, the conventional dyeing methods present several problems; high-temperature dyeing [8], excessive use of water, and discharge of several chemical additives [9] and difficulties involved in dyeing blends of PET and natural fibers, which do not stand high temperatures, all of which have led to the search of solutions and the publication of several works [10–12]. Studies developed by our group [13,14] show that modifying PET fibers and films with *N*,*N*-dimethylacrylamide(DMAAm) improves dye sorption with significantly shorter dyeing times.

UV light has been used to modify PET surface [15]. PET irradiation with UV light promotes chemical surface

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modifications and improves wettability. In recent studies [16], it was observed that PET treatment with UV light and *N*,*N*-dimethylacrylamide (DMAAm) decreases surface tension and favors dye incorporation.

Response surface methodology (RSM) [17] has proved to be valuable in studies involving a great variety of problems. An important example is the determination of optimum experimental conditions. In RSM, a polynomial response surface is generally used to describe the relationship between a response variable Y and predicting variables X. The functional relationship for a quadratic model with k independent variables is often:

$$Y = \xi_0 + \sum \xi_i X_i + \sum \xi_{ii} (X_i)^2 + \sum \xi_{ij} X_i X_j + E,$$
$$i, j = 1, 2, 3 \ldots k$$

In this work, factorial design was used to evaluate the effect of the factors associated to pre-treatment and dyeing UV light- and DMAAm-modified PET in relation to dye incorporation. RSM was used to determine the best treatment and dyeing conditions for PET knitted fabrics. Dye incorporation results were analyzed along with the diffusion coefficients calculated for each dyeing system studied.

2. Experimental

2.1. Materials

This work was conducted with commercial poly(ethylene terephthalate) knitted fabrics (provided by Seda Têxtil Ltda) made of 174/22 dTex yarns with 18 μM diameter filaments. Dyes (Dy Star): Navy Blue Dianix ER-FS 200 (CI Disperse Blue 79) and Red Dianix E-FB (CI Disperse Red 60). Modifier: *N*,*N*-dimethylacrylamide (Fluka). Fig. 1 shows the dye, modifier, and PET chemical structures.

2.2. Pre-treatment of PET knitted fabrics

Non-modified PET knitted fabrics were first washed for 6 h and dried. Then, they were subjected to UV light and DMAAm treatments.

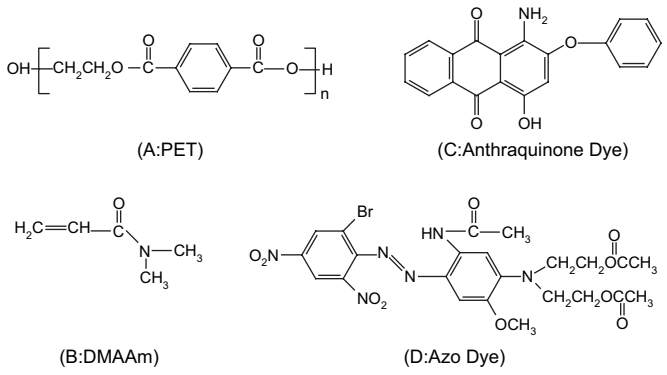

Fig. 1. (A): Poly(ethylene terephthalate), (B): *N*,*N*-dimethylacrylamide, (C): CI Disperse Red 60 (Red Dianix E-FB), and (D): CI Disperse Blue 79 (Navy Blue Dianix ER-FS 200).

UV light irradiation: non-modified and DMAAm-modified knitted fabrics were placed in a booth with a 250 W high-pressure mercury vapor lamp from EMPALUX as a UV light source. Lamp emission peaks were at 254, 263, 297, 303, and 365 nm [18]. The samples were placed at a fixed distance of 5.5 cm from the source. The UV light booth was kept closed and did not have vents. Under these conditions, the sample was heated and consequently subjected to thermal treatment. To exemplify, Fig. 2 shows the sample-heating curve inside the booth during UV light treatment.

DMAAm treatment: non-modified knitted fabric and UV light-treated knitted fabric were immersed into the modifying solvent, DMAAm, at 85 °C for different lengths of time.

Two types of pre-treatment were used in this work:

(i) DMAAm sorption followed by UV light exposure (DMAAm → UV light)
(ii) UV light exposure followed by DMAAm sorption (UV Light → DMAAm).

2.3. PET knitted fabric dyeing

Non-modified and DMAAm → UV light- and/or UV → DMAAm light-modified PET knitted fabrics were dyed under different conditions, according to factorial designs and star designs. The PET knitted fabrics were immersed into a dye aqueous dispersion 1:150 (g/mL). It was used at a concentration of 3 wt.% of dye in relation to the PET knitted fabrics. Dyeing was performed, under stirring, in a glass cell coupled to a thermostatized water bath at 85 °C.

Table 1 shows the factors and values for the levels used in the complete factorial designs for both dye types. The main and the interaction effects of DMAAm treatment time, UV radiation exposure time, and dyeing time on the Dm/KFm (dye mass/knitted fabric mass) response were analyzed.

The best modification and dyeing conditions were determined by response surface methodology (RSM). Factors and

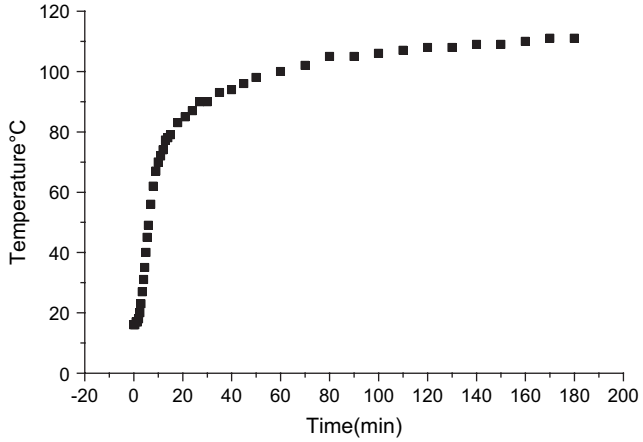

Fig. 2. Heating curve of PET sample inside the booth during UV light treatment.