

A study on effect of polar and non-polar solvent as carrier in dyeing of polyester with disperse dye

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ABSTRACT: Dyeing behavior of the disperse dye, Disperse Violet 1, on polyester fiber in the presence of polar and non-polar solvents as carrier was investigated in this work. Many solvents can act as carrier in dyeing of polyester with disperse dye. The carrier acts as swelling agent, opening the fiber pores so that the dye molecules can penetrate more rapidly into the fiber. The results revealed that the non-polar solvent (benzene and toluene) showed good carrier action as compared with the polar solvents (ethanol and methanol). Dyeing with benzene with least polarity as compared with the other solvents displayed the highest dye exhaustion (i.e. highest dye uptake by the fiber) of 82.25%.

KEYWORDS: Carrier, Polar and non-polar solvents, Polyester, Disperse dye

I. INTRODUCTION

Polyester fiber is the most widely used synthetic fiber due to its good physical and chemical properties [1, 2]. Polyester fibers are thermoplastic with low moisture absorption, and very good resistance to abrasion. Like nylon, it has high tensile strength which enables it to be used not only for clothing but also for industrial purposes and sail cloth. Polyesters, especially poly(ethylene terephthalate) (PET) were manufactured as industrial products by ICI (UK, 1949) and Du Pont (USA, 1953) soon after the technology of manufacturing was developed by Whinfield and Dickson in 1946 [3].

It is also well known that PET fiber is dyed using disperse dyes at high temperatures of 120-130 °C, owing to its hydrophobic nature and highly compact molecular structure [4]. Polyester fiber has a highly compact and crystalline structure, and is markedly hydrophobic. For this reason, its aqueous dyeing is carried out at high temperature and high pressure using disperse dyes. These synthetic fibers

have been dyed by two principal methods: (1) Dyeing at temperature above 100 °C in pressure vessels. (2) Dyeing at temperature of 100 °C or lower by adding organic compounds called carriers to the dye bath to increase the dyeing rate [5]. The dyeing of polyester can be divided into several parallel processes such as dissolution and redissolution of disperse dye, transfer of dissolved dye from bulk solution to the fiber surface, diffusion and adsorption of dye at the fiber surface, and diffusion from the surface into the interior of the fiber [6, 7]. It is well known that the additives in the dye bath affect the dyeing processes.

The dyeing of polyester textile materials with disperse dyes presents a number of practical problems to the textile industry. These problems are principally associated with unevenness, lack of reproducibility, and barre effects, which are thought to have their origin essentially in structural non-uniformities of the polyester yarns [8]. During numerous manufacturing and processing steps prior to dyeing, the polyester material is subjected to various thermomechanical treatments which may give rise to variations and non-uniformities in structure. The effects of such thermally-induced structural modifications on the dyeing behavior of polyester have been systematically investigated by a number of workers, most notably by Marvin [9] and by Dumbleton *et al.* [10]. It is known that a number of organic solvents can produce significant structural modifications in polyester fibers, and that these modifications differ significantly from those induced by purely thermal treatments [11]. Solvent-carrier systems have been utilized to improve the dyeability of polyester materials [12].

In this study, carrier action of two polar (ethanol and methanol) and non-polar (benzene and toluene) solvents was investigated in terms of % exhaustions (dyes uptake by the fiber) and different

concentrations of the solvents were employed. The results obtained showed that the non-polar solvents exhibit good carrier action as compared with the polar solvent.

II. EXPERIMENTAL

2.1. Materials

Polyester fabric (Dacron@ 70/34) obtained from E. I. du Pont de Nemours & Co. Polyester fiber, Disperse dye, C. I. Disperse Violet 1 (1,4-diaminoanthraquinone), was purchased from Aldrich Chemical and was used without further purification Structure, ¹³C, and H1 NMR of the were depicted in Fig. 1, Fig. 2a and Fig. 2b respectively. Benzene (99.8%), ethanol (99.8%), methanol (99.8%), toluene (99.8), Nitric acid (65%) was purchased from Merck.

2.2. Pretreatment of the polyester fiber

2.3.1 Desizing

$$\text{Volume of the required} = \frac{\text{weight of the fabric} \times \% \text{ shade}}{\text{concentration of stock solution}} \quad (1)$$

$$\text{Total volume of dyebath} = \text{weight of fabric} \times L - R \quad (2)$$

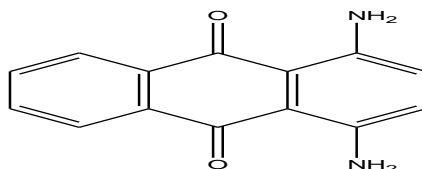


Fig. 1. Structure of Disperse Violet 1.

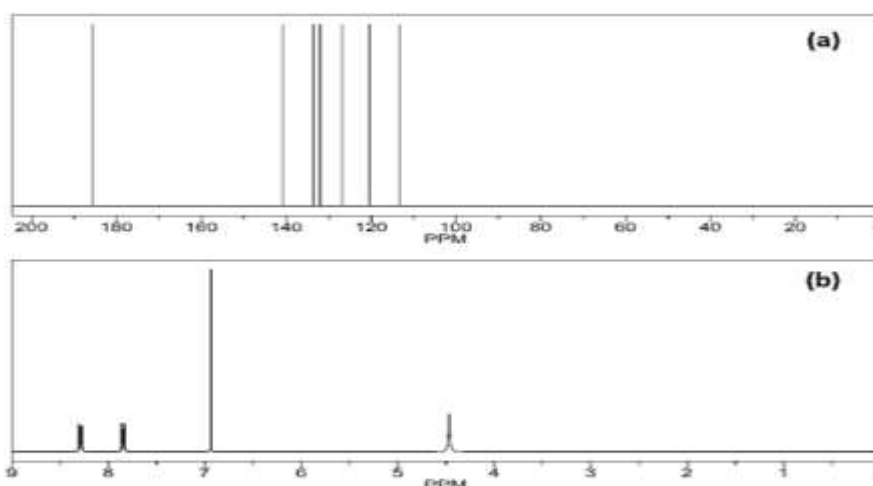


Fig 2. (a) ¹³C NMR and (b) ¹H NMR of Disperse dye violet 1.

In the dyeing procedure, 2ml of the dye stock solution as calculated from eq. (1) was pipetted into a beaker and 0.2ml, 0.4ml, 0.6ml and 0.8ml of toluene (as carrier) was added into the

The polyester fiber was impregnated with water and stored for 24 hours at room temperature and washed. It was then boiled with distilled water for 30min and washed again, then dried at room temperature.

2.3.2 Scouring

The polyester fiber was boiled in detergent solution for 15 minute. It was then rinsed with distilled water and dried in a desiccator at room temperature.

2.3 Dyeing

1% of the dye solution was prepared and used as the stock solution. In this study, %depth of the shade is 2, L-R is 30:1 and the weight of fabric is 1g. The volume of the dye required and the total volume of dyebath were calculated from eq. (1) and (2) respectively.

beaker and the solution was made up to 30ml (Total dye bath as calculated from equation (2)) with distilled water. 1g of the desized and scoured polyester fibre was immersed in the dye bath at 100

°C using water bath and dyed for 30 minutes. After duration of dyeing, the dyed fibre was removed and thoroughly rinsed with distilled water. The liquor ratio was maintained by adding distilled water to replace the one lost by evaporation. This procedure was repeated using benzene, methanol and ethanol as carrier. The procedure was also carried out by keeping the carrier (0.6 mL) and temperature (100 °C) constant for 10 min, 20 min, 30 min, 40 min and 60 min, and keeping carrier (0.6 mL) and time (60 min) constant for 40, 60, 80, 100 and 120 °C.

After dyeing, a 2 ml sample of the residual dye bath was taken to measure the absorbance value using a UV-Vis spectrophotometer (Perkin-Elmer, Lambda 35) and the percentage dye exhaustion (%E) was calculated using eq. (3).

$$\%E = \frac{A_i - A_f}{A_i} \quad (3)$$

Where A_i and A_f are the absorbance of the dye before and after dyeing.

2.4 Measurement of Color Fastness Properties

The color fastness to washing of the polyester fabrics dyed using toluene, benzene, methanol and ethanol was evaluated according to "ISO 105-C06 A2S: 2010" with L-R of 1:50. The changes in the shade and the staining of the adjacent fabric were assessed using grey scales [13].

III. RESULTS AND DISCUSSION

3.1. Effect of Concentration of the solvents as carrier.

The rate of dye diffusion can be fortified by enhancing the permeability of the fabrics, by

increasing the ability of the fabrics to swell. This can be obtained by additional compounds with smaller molecules than the dye molecules in the dye bath. These compounds are known as carriers, as a result of their small molecule size, and they rapidly distribute into the fabrics. The use of carriers is a well-known method for increasing the speed of the distribution of dyes in polyester fabrics. Carriers incite the loosening of the fabric microstructure [14]. In this work, four different solvents (ethanol, methanol, toluene and benzene) were employed as carrier for dyeing of polyester.

Plots of percentage exhaustion during polyester dyeing as a function of concentration of the solvents (ethanol, methanol, toluene and benzene) as carrier at 100 °C for 120 min are depicted in Fig. 3. As seen from the figure about 21% dye exhaustion was observed in the absence of all the solvents (ethanol, methanol, toluene and benzene). The percentage exhaustion increases significantly as the concentration of the solvents increases from zero to 4% and slightly change from 4 to 5% for all the solvents. Among all the solvents (employed as carrier), the two non-polar solvents show higher dye exhaustion (79.87% for benzene and 70.85% for toluene) as compared to the two polar solvents (39.31% for ethanol and 32.98% for methanol). The results revealed that, among the four solvents used in this work, benzene has a highest carrier action in dyeing of polyester at 100 °C.

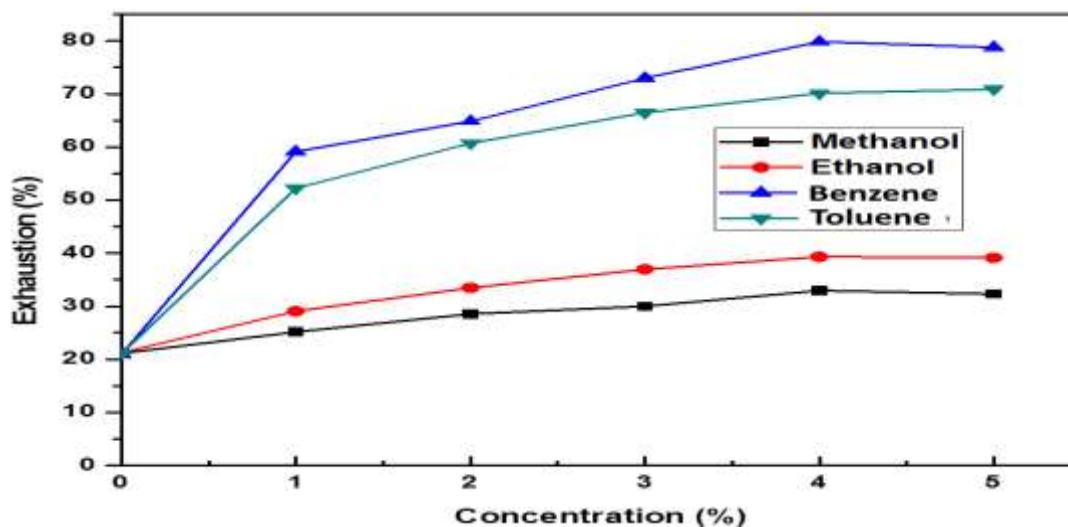


Fig. 3. Effect of concentration of the solvents as carrier on percentage exhaustion of the dye for 120 min polyester dyeing.

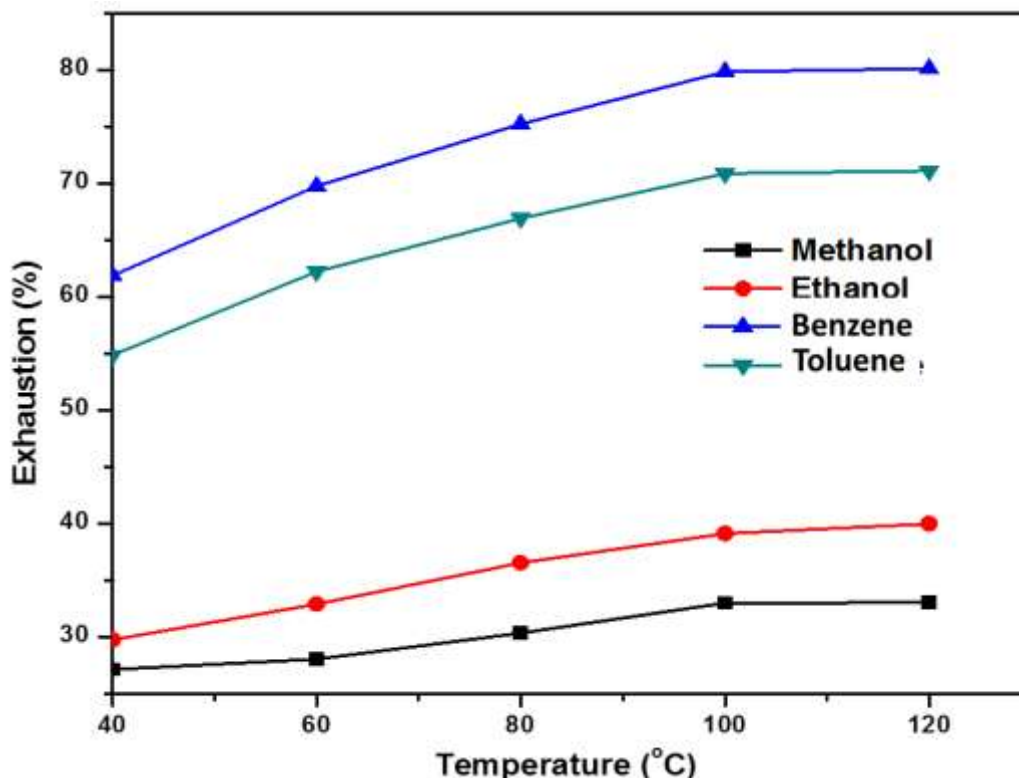


Fig. 4. Exhaustion of disperse dye on polyester as a function of temperature.

3.2 Effect of dyeing temperature

In order to study the effect temperature on exhaustion of dye on polyester for the different solvent (4% of ethanol, methanol, toluene and benzene) employed as carrier, polyester fibers were dyed with disperse dye at various temperature ranging from 40 to 120 °C. Fig. 4 shows the exhaustion of dye on polyester as at different temperature for ethanol, methanol, benzene and toluene (as carrier). It can be seen from the figure, the exhaustion of dye on polyester increased with increasing application temperature for all the solvents. This may be attributed to the higher kinetic energy of the dye molecules, the higher diffusional power within the polymer substrates and the higher fiber swelling effect [14, 15]. The results revealed that the two non-polar solvent exhibit higher carrier action with 71.09 and 80.11% dye exhaustion for toluene and benzene respectively, than the two polar solvents with 33.04 and 39.99% dye exhaustion for methanol and ethanol respectively.

3.3 Effect of dyeing time

Having found out that dyeing of polyester with disperse dye employing ethanol, methanol, toluene and benzene as carrier was optimally achieved at temperature of 120 °C and carrier concentration of 4%, a further set of

experiments were conducted to examine the effect of dyeing time on dye exhaustion by the polyester fiber. The result depicted in Fig. 5 reveals that the dye exhaustion by the polyester fiber drastically increase with increasing dyeing time from 0 to 140 for the non-polar solvent (toluene and benzene) and 120 for the polar solvents (ethanol and methanol). From the time dependence of the dye exhaustion, the period for which equilibrium sorption was determined as 140 and 120 min at 120 °C for non-polar and polar solvents (as carrier) respectively.

3.4 Dyeing kinetics rate constant

There is general consensus that dyeing process involves three continuous steps. The first step is the diffusion of dye from aqueous dye bath on to the fiber. The second step is the adsorption of dye into the outer layer of the fiber. And the last step is the diffusion of dye into the fiber inside from the adsorbed surface. The second step, the actual adsorption process, is generally assumed to be much more rapid than either of the other diffusion steps. Of the two diffusion steps, the diffusion into the inner layer is much slower than the movement of dye through the aqueous solution due to the physical obstruction of dye diffusion presented by the network of fiber molecules [1]. The overall rate of these three steps are refers to dyeing rate. The

dyeing rate (dye exhaustion as a function of time) using different solvent are presented in Fig. 5 and the dyeing rate constants were calculated using eq. (4) [2, 16]

$$K_t = \frac{x}{(1-x)^2} + 0.5 \ln \frac{1-x}{1+x} \quad (4)$$

where x is the quotient between the dye concentration on the fiber at time t and the initial time in the dye-bath, K_t is the dyeing rate constant and t is the time of the kinetics examined. Table 2 shows the dyeing rate constants employing different solvents, calculated from Equation (4).

Table 1. Dyeing rate constants and dye exhaustion after 120 min

Solvents	K	Exhaustion after 120 min (%)
Benzene	0.5137	79.97
Toluene	0.4504	70.10
Ethanol	0.2534	39.45
Methanol	0.2200	34.25

According to Table 2, the dye rate constants are in the order of Benzene > toluene > ethanol > methanol as expected

3.4 Color fastness of the dyed polyester

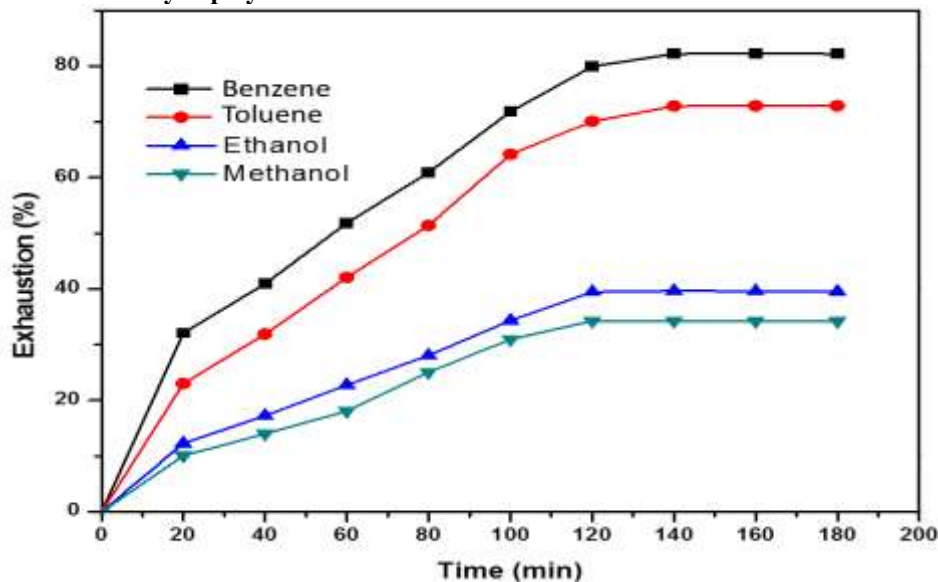


Fig. 5. Time dependence of dye exhaustion by the polyester fiber at 120 °C and 4% carriers concentration.

Table 2. Color fastness to washing

Solvent employed as carrier	Color Change	Color staining	
		Cotton	Polyester
Toluene	4	4-5	4-5
Benzene	4-5	4-5	4-5
Methanol	4	3-4	4-5
Ethanol	4	3-4	4-5

Toluene	4	4-5	4-5
Benzene	4-5	4-5	4-5
Methanol	4	3-4	4-5
Ethanol	4	3-4	4-5

IV. CONCLUSION

Carrier action of polar solvents (methanol and ethanol) and non-polar solvents (toluene and benzene) was investigated on dyeing of polyester fiber with disperse dye. Effect of carrier concentration, dyeing temperature and time on dye exhaustion were studied. The results revealed that the non-polar solvents have higher carrier action as compare to the polar solvent. Benzene with least polarity displayed highest dye percentage exhaustion of 82.25% at optimum condition of 4% carrier concentration, 120 °C and 140 min.

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