The effect of heat setting on the dyeability of differentially dyeable polyester fibres

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Apparent diffusion coefficients of two disperse dyes for so-called easily dyeable/cationic-dyeable polyester (ED-CDPET) and cationic-dyeable polyester (CDPET) fibres of identical linear density and sulphonic acid group content have been calculated. It was found that the diffusion coefficients of dyes for ED-CDPET were far greater than those of dyes for CDPET. The dyeability at the boil without carrier, using disperse and cationic dyes on various ED-CDPET and CDPET fibres, has been studied. ED-CDPET was found to have higher dyeability at all levels of heat setting (irrespective of the dye used). The finest ED-CDPET fibres showed maximum dye uptake as a result of increased surface area. Heat setting in the taut condition reduced dye uptake.

INTRODUCTION

The development of so-called easily dyeable/cationic-dyeable polyester (ED-CDPET) fibres is of great significance for apparel textiles, because these fibres can be dyed at the boil. Such easy dyeing conditions are quite appropriate for ED-CDPET/wool blends in which wool can be readily protected from damage during dyeing. This relatively low-temperature dyeing process also aids energy conservation. A lot of published data are available on the effect of heat setting on the dyeability of polyester, including information on so-called cationic-dyeable polyester (CDPET), which has been reported from this laboratory [1–3]. However, no work has so far been reported on the effect of thermal treatment on the dyeability of the ED-CDPET fibres. Hence this paper discusses some work carried out in this area.

EXPERIMENTAL

Materials

ED-CDPET flat filament yarns of 2.3, 1.7 and 1.2 dtex per filament and CDPET flat filament yarns of 2.3 dtex per

filament, all having nominally 1.5 mol% dimethyl ester of 5-sulphoisophthalic acid (sodium salt) (DMS), were used. In addition a sample of CDPET flat filament yarns of 2.3 dtex per filament with a nominal 2.5 mol% DMS was included in the study. All the samples were obtained from J K Synthetics Ltd, and were scoured before use.

The dyes used were Foron Blue SE-2R (CI Disperse Blue 183), Foron Brilliant Orange E-RL (CI Disperse Orange 25) and Sandocryl Blue B-3G (CI Basic Blue 3), supplied by Sandoz (India) Ltd. All were used as supplied.

Heat setting

Heat setting of the yarns was carried out in a hot-air curing chamber in slack and taut conditions for 90 s at 110–200°C.

Calculation of diffusion coefficients

Diffusion coefficient D was calculated according to Eqn 1 [14]:

$$D = \frac{0.04919\, l^2}{t_{1/2}} \qquad (1)$$

where l is diameter of the fibre (cm) and $t_{1/2}$ is the time of half dyeing, i.e. time at which $C_t/C_\infty = 0.5$. All the dyeings were carried out in an infinite dyebath at 100°C. The diameters of the filaments were measured by using a projection microscope.

Dyeing

Dyeing (3.0% shade) was carried out for 60 min at 100°C with continuous stirring. The dyebath contained anionic dispersing agent (1 g/l) and acetic acid (2 g/l) to maintain the pH at 5.0. With cationic dyeing, the bath also contained sodium sulphate (6 g/l). The fibre samples were cold washed with acetone and then soaped with nonionic detergent (2 g/l) for 15 min at 60°C.

Estimation of dye on the fibre

The amount of cationic dye on the fibre was determined by dissolving the dyed fibre in *o*-cholorophenol. In disperse dyeing the dye was extracted in dimethyl formamide (DMF) for 60 min at 100°C. The absorbance of dye solutions and extracts was measured using a Shimadzu UV-1201 UV-VIS spectrophotometer at appropriate wavelengths.

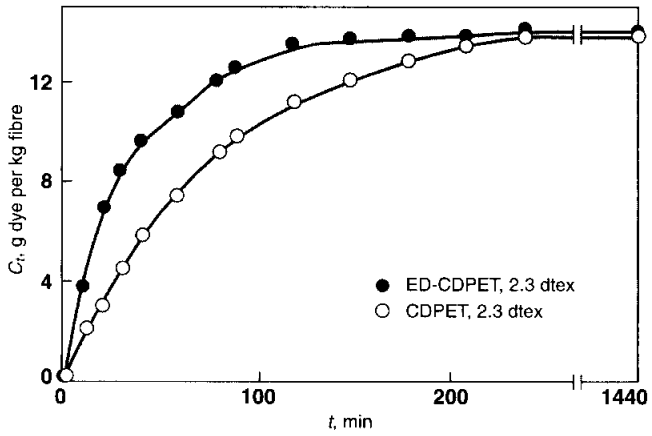

Figure 1 Relationship between dyeing time and dye uptake for CI Disperse Blue 183

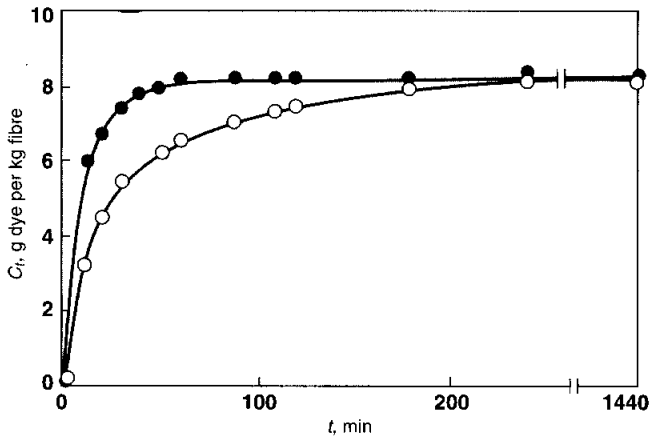

Figure 2 Relationship between dyeing time and dye uptake for CI Disperse Orange 25 (for key see Figure 1)

Table 1 Times of half dyeing and diffusion coefficients of disperse dyes on ED-CDPET and CDPET

	CI Disperse Blue 183		CI Disperse Orange 25	
Fibre	$t_{1/2}$ (min)	D (cm²/s)	$t_{1/2}$ (min)	D (cm²/s)
ED-CDPET	20	10.49×10^{-11}	6	34.97×10^{-11}
CDPET	50	4.19×10^{-11}	18	11.65×10^{-11}

RESULTS AND DISCUSSION

ED-CDPET and CDPET filaments of 2.3 dtex and identical sulphonic acid group content were dyed with CI Disperse Blue 183 and CI Disperse Orange 25, respectively high and low r.m.m. disperse dyes. The amount of dye on the fibre (C_t) at different times (t) is plotted for both dyes in Figures 1 and 2. The time of half dyeing was obtained from these figures and hence the diffusion coefficients (Table 1).

The $t_{1/2}$ value of ED-CDPET was lower than that of CDPET, indicating a higher dyeing rate, further confirmed by the respective diffusion coefficients. Faster diffusion in ED-CDPET could be attributed to the fibre's more open structure. As far as the effect of molecular mass of the disperse dye was concerned, in any given fibre the low r.m.m. dye (CI Disperse Orange 25) exhibited a lower $t_{1/2}$ value or a higher diffusion coefficient compared with those values for CI Disperse Blue 183.

Figure 3 shows the relationship between disperse dye uptake on ED-CDPET and CDPET fibres and heat-setting temperature. With all the samples, the dye uptake decreased gradually to a minimum (at around 150°C) and subsequently increased. This was because, as primary

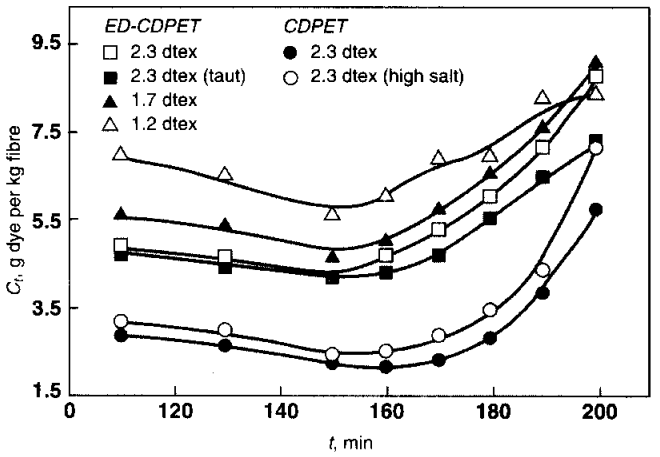

Figure 3 Relationship between heat-setting temperature and dye uptake for CI Disperse Blue 183

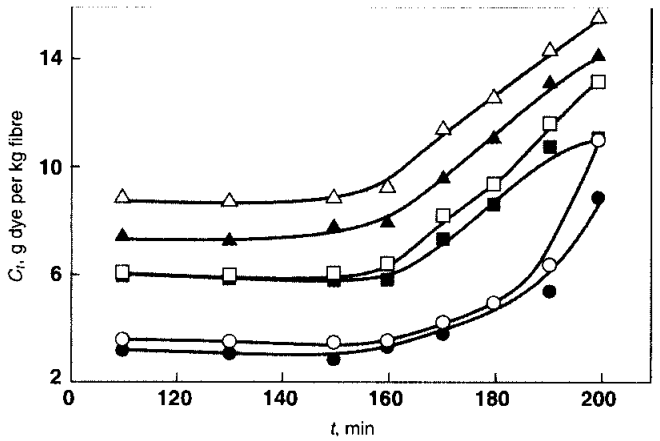

Figure 4 Relationship between heat-setting temperature and dye uptake for CI Basic Blue 3 (for key see Figure 3)

crystallisation took place at relatively low heat-setting temperatures, the number of small crystals continued to increase and the free volume available to each crystal commensurately decreased, reflected as a gradual decrease in dye uptake. Beyond the critical temperature, these small crystals melted and fused to form larger crystals, drastically reducing orientation of chain molecules and also increasing the free volume available for each crystal, since the number of crystals continued to decrease. The overall effect was one of progressive increase in dye uptake.

The actual level of dye uptake for ED-CDPET was much higher than that for CDPET at any given heat-setting temperature, indicating the former's better dyeability. Varying the linear density of ED-CDPET, keeping the sulphonic acid group content the same, gave a similar result. However, as the linear density was decreased, the dye uptake values increased at any given heat-setting temperature, because of the greater surface area available for dye diffusion.

The CDPET with the higher sulphonic acid group content was also dyed, and showed a greater degree of disperse dye uptake. This was probably because of the relatively low crystallinity of the CDPET used.

Dye uptake on taut-annealed samples of ED-CDPET was found to be markedly lower than that of slack-annealed samples.

CI Disperse Orange 25, a disperse dye of low r.m.m., gave a similar trend to that depicted in Figure 3. The absolute values of the dye uptake in this case were much higher than those for CI Disperse Blue 183, reflecting the differences in diffusion coefficient already discussed. For this reason, preliminary heat setting of the fibre at different temperatures did not yield significant differences in dye uptake as compared with the behaviour on unset fibres.

When dyeing with the cationic dye CI Basic Blue 3, dye uptake increased sharply on fibres heat set at temperatures over 150°C (Figure 4). Cationic dyeing, governed as it is by electrostatic forces, depends greatly on the extent of dye diffusion in the fibres. At higher heat-setting temperatures dye diffusion and extent of salt linkages increased, giving higher dye uptake. This behaviour was further enhanced due to an increase in the carboxylic acid group content in the fibres, caused by thermal degradation.

Uptake of cationic dye on ED-CDPET was higher than that on CDPET, even when both fibres had identical sulphonic acid group content. This further confirmed that, in cationic dyeing, the actual number of the sulphonic and carboxylic acid groups and their accessibility to the dye cations both influence dyeing performance.

CONCLUSION

So-called easily dyeable/cationic-dyeable polyester (ED-CDPET) exhibits better dyeing properties than so-called cationic-dyeable polyester (CDPET) of identical linear density and sulphonic acid group content, for all the disperse and cationic dyes studied, and at all levels of heat setting. While disperse dyeing is solely governed by a diffusion mechanism, cationic dyeing performance depends to a great extent on the number of anionic sites present and the extent of diffusion, which in turn is related to the accessibility of the fibre to the dye.

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