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Storage Stability of Extracted Dye from the Surface of Polyester Fabric in Non Aqueous Cleaning Solvents

Gboyega O. Oyeleke[1*], Mudasiru A. Salam[1], Olusola A. Adedayo[2], Ibraheem A. Abdulazeez[2] and Ajisola A. Adebisi[2]

[1]Department of Science Laboratory Technology, Osun State Polytechnic, P.M.B. 301, Iree, Nigeria.
[2]Department of Applied Science, Osun State Polytechnic, P.M.B. 301, Iree, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author GOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAS and OAA managed the analyses of the study. Authors IAA and AAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This research work focused on extracting dye from the surface of dyed polyester fabric and also investigates the effect of exposing the extracted dye solution to diffused light and changes in temperature which are common processes in dry cleaning industries. This is to establish the stability of the extracted dye in non aqueous solvents. Two commonly used dry cleaning solvents-perchloroethylene (PCE) and tetrachloromethane (TCM) were used to extract disperse blue 1 dye from the surface of dyed polyester fabric obtained from a previous work. The storage stability of the extracted dye at room temperature in diffused light as well as thermal stability at 20°C, 30°C and 50°C in the two solvents is reported. The daily visual check on the colour of the extracted dye solution on exposure to diffused light for a period of 14 days was found to be stable for 5 days in PCE while it lasted for 9 days in TCM before fading. Spectrophotometry analysis of the extracted dye solution was found to be thermally stable in TCM at the various temperatures used for the experiment relative to PCE where concentration of the extracted dye was found to decrease. The

**Corresponding author: Email: mr.oyeleke@yahoo.com;*

results obtained therefore serves as useful standard for choosing suitable solvents during dry cleaning of dyed fabrics to prevent adverse effects on the aesthetic nature of the fabric surface dye.

Keywords: Dye; non-aqueous; stable; storage; light; thermal; dry-cleaning.

1. INTRODUCTION

Polyester fibres generally exhibit low surface energy and limited chemical reactivity, resulting in poor wettability and weak adhesive bonding. Polyester is often blended with other fibres such as cotton to get the best of both materials. It can be used for fashionable dresses but most adopted for its ability to resist wrinkling and its easy wash ability. Polyester fabrics are highly stain-resistant and the classes of dyes which can be used to alter the colour are known as disperse dyes [1]. There are essentially three ways in which the solvent pretreatment can be helpful in improving disperse dyeing on polyester [2]. Firstly, the solvents can modify the fibre structure in a more or less temporary way by some structural changes. Secondly, the solvent can be used to modify fibre structure irreversibly or permanently by creating more voids in addition to reduction in glass transition temperature and crystallinity of the fibre. Thirdly, the solvent can dissolve out oligomers and homogenize the fine structural differences which will provide increased ability to open up the fibre surface for deposition of more dyestuff [3].

The effects of pretreatment with mixture of solvent may not be the same, intersolvent interactions may be proportional to composition of solvent mixture. The glass transition temperature of a crystallizable polymer may be sufficiently depressed by the presence of a solvent in such a way that segmental mobility becomes sufficient to permit crystallization. Penetration of the solvent into the amorphous regions involves the breakdown of intermolecular bonds and produces increased segmental mobility of the polymer chains that is reflected in the lowering of the glass transition temperature. During the deformation of such plasticized polymeric fibres, the forces that are transmitted through the swollen amorphous layers to the crystalline domains are small and do not cause large-scale deformation of the crystallites.

Removal of the solvent from the polymer results in the partial restoration of the original properties, depending on the extent of fibre shrinkage that has taken place. Dry cleaning of polyester fabric is of common use to remove soils, dirts and stains with non-aqueous solvents. This process is however not completely dry because fluids are used to immerse the garments. It is used to clean delicate fabrics that cannot withstand the rough and tumble of aqueous hand washing and drying that is considered labour and time intensive. In dry cleaning, textile materials are soaked in the solvents that are easily and readily recycled [4]. The process involved selective solubilisation of stains on a textile or other polymeric materials which would otherwise dissolve in aqueous cleaning agents at very high temperature. This may in turn damage, degrade or destabilize the fibre or dye components.

Chlorinated solvents are of common use in textile dry cleaning while their toxicity especially that of perchloroethylene was grouped to be “moderate to low” and human injury are not rampant despite the wide usage in the dry cleaning industries [5]. Many researchers have worked on solvent pretreatments and dyeing of polyester and its blends using several methods [6,7,8] with concerted efforts only on improving the morphology and dye uptake of the fabrics while the stability of the fabric surface dye (FSD) during dry cleaning with these solvents was left uncared for. Solvent effects on organic reactivity and absorption spectra showed that the photo-physical behavior of a dissolved dye depends on the nature of its environment such as intensity and shape while maximum absorption wavelength of the absorption band of the dye depends on the solvent- solute interactions and solvent nature [9].

Cleaning the surface of polyester fabric may adversely affect other important components of the material such as dye if not handled carefully and this has caused problems between dry cleaners and users. Also during processing, many fabrics may either be over dyed or unevenly dyed and requires adjusting or removing of the excess dye with non aqueous solvents to achieve desired shade. This process may involve keeping the extracted dye (in the solvent) for some period of time before the completion of the reduction clearing or the leveling process. This research work therefore aimed at extracting dye from the surface of dyed polyester fabric using two dry cleaning solvents

(PCE and TCM) and to assess visually, the stability of the extracted dye solution to diffused light over a period of 14 days and to determine spectrophotometrically, the possible changes in the concentrations of the extracted dye due to variation in temperature of the solution in order to give better information on maintenance of the aesthetic nature of dyed fabrics to textile processors and users.

2. METHODOLOGY

2.1 Extraction of Dye from the Surface of Dyed Polyester Fabric

Pieces of 20 mg each of dyed polyester fabric samples (using disperse blue 1 dye) from previous research work [10] were weighed accurately into small conical flasks and were soaked with about 20 ml of the dry cleaning solvents; perchloroethylene (PCE) and tetrachloromethane (TCM). The flasks were placed in a thermostatically controlled water bath at room temperature coupled with a mechanical shaker. The entire time used for the extraction was 600 s but dye extracts were obtained at 150, 300, 450 and 600 s, transferred into a 100 ml volumetric flask, allowed to attain room temperature and finally diluted up to mark with the solvents.

2.2 Determination of the Amount of Dye Removed

The concentrations of the dye extracts were measured spectrophotometrically using spectrometer 721 (2000 model) at 605 nm (λ_{max}). The concentrations of the dye extracts were thereafter determined from the calibration curves of the disperse dye in each of the solvents [11].

2.3 Calibration Curve of the Dyestuff

Dye solutions of varying concentrations were prepared and their absorbances determined at the wavelength of 605 nm for which it was found to show maximum absorbance and the validity of Beer-Lambert law established by a linear correlation between the dye concentration and the optical density [12].

2.4 Storage and Thermal Stabilities of the Extracted Dye in the Solvents

The stability of the extracted dye to diffused light and thermal treatments in the two solvents was carried out using the modified methods of Madan and Khan [13] where the dye solutions were stored at room temperature in diffused day light over a period of 14 days for storage stability determination. The extracted dye solutions were also heated in a thermostatically controlled water bath at 600 s for 20°C, 30°C and 50°C (temperature below the boiling points of PCE and TCM) for thermal stability study. The range was chosen to include lower and higher temperature values relative to 25°C recommended for dry cleaning of textile materials [14] in order to establish the effect of temperature on the stability of the dye in the solvents. The stability of the dye to light in the solvents was monitored visually while the change in concentrations of the dye extracts due to heat were measured spectrophotometrically using spectrometer 721 (2000 model) at 605 nm [11].

2.5 Tensile Properties Determination

The tensile properties of the polyester fabric after dye extraction in terms of elongation at break and work of rupture were measured on Instron tensile testing machine (Tensorapid V.8 model) at an extension rate of 100%/min using a gauge length of 5.0 cm and load cell of 0-5 N.

3. RESULTS AND DISCUSSION

3.1 Results

The results of the calibration of the dye stuff in the two dry cleaning solvents are presented in Table 1, Figs. 1 and 2 to determine the effect of thermal treatment on the extracted dye.

After the extraction of the dye from the surface of the dyed polyester fabrics using PCE and TCM, the concentrations of disperse blue 1 obtained are shown on Table 1. Increase in the amount of dye removed with increase in extracting time was observed until equilibrium at 600 s was reached. It was noted that TCM extracted more dye than PCE throughout the extraction period; this observation was similar to the report of Oyeleke et al. [11] on the laundering of polyester fibre in selected chlorinated solvents where TCM was found to remove more dye compared to other solvents. This observation could be explained in terms of the level of partition coefficient between the dye and TCM compared to that of PCE.

Table 2 showed the visual observation of the stability of the extracted dye at room temperature. Extracted dye in TCM was found to be more stable to diffused day light than in the PCE. The colour of the extracted dye in PCE was observed to be stable for 5 days while it lasted for 9 days in TCM before fading. The observations were similar to the report of Madan and Khan, [13] for stability of disperse dyes in chlorobenzene. Our observations could be explained in terms of the close solubility parameters of the dye and the solvents [15]. The solubility parameter of the dye is expected to be close to that of the polyester fibre (10.7) while that of PCE and TCM were 9.76 and 8.65 respectively. The dye will be more soluble and unstable in PCE because of the closeness in their solubility parameter values. This may therefore account for the breakdown (fading) of the dye molecule in PCE in the presence of diffused light more easily than in TCM.

Table 1. Amount of dye removed from dyed polyester fabric at room temperature

Extraction time (s)	Solvent	Amount of dye removed (mg/g)
150	PCE	17.3
	TCM	29.3
300	PCE	25.7
	TCM	41.3
450	PCE	28.9
	TCM	50.7
600	PCE	29.4
	TCM	51.2

Results obtained for PCE (from Fig. 1) and for TCM (from Fig. 2)

Table 2. Visual observation of storage stability of the extracted dye in the solvents at room temperature

Solvent	Storage period (day)	Physical observation
PCE	14	Colour of the dye was found to be stable in the solvent until 5th day
TCM	14	Colour of the dye was found to be stable in the solvent until 9th day

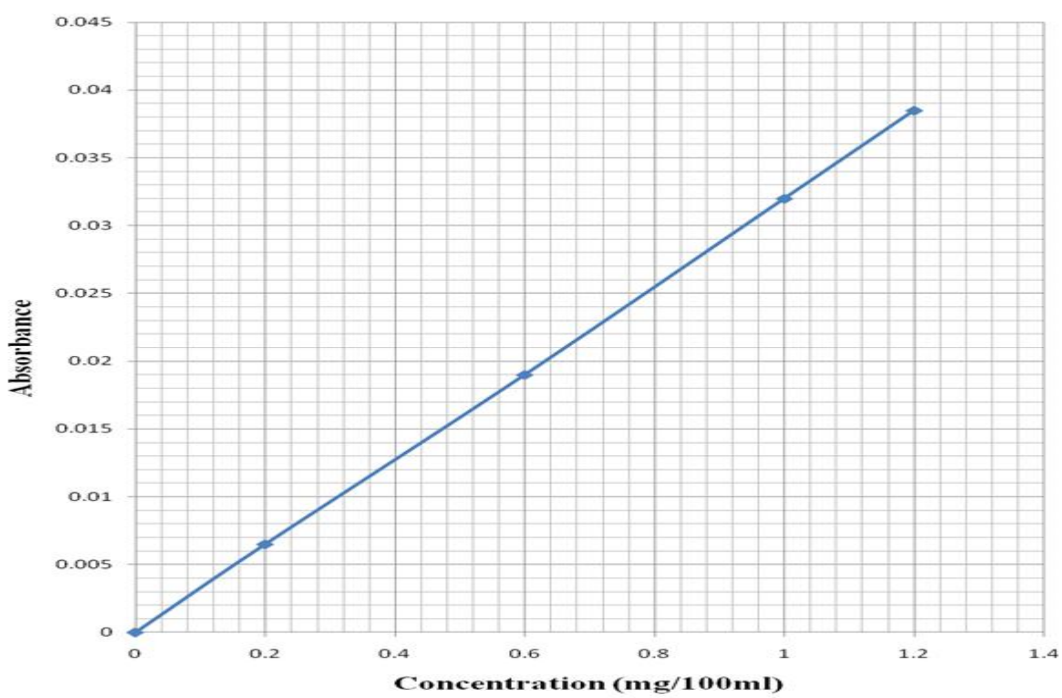

Fig. 1. Calibration curve of disperse blue 1 dye in PCE at 605 nm

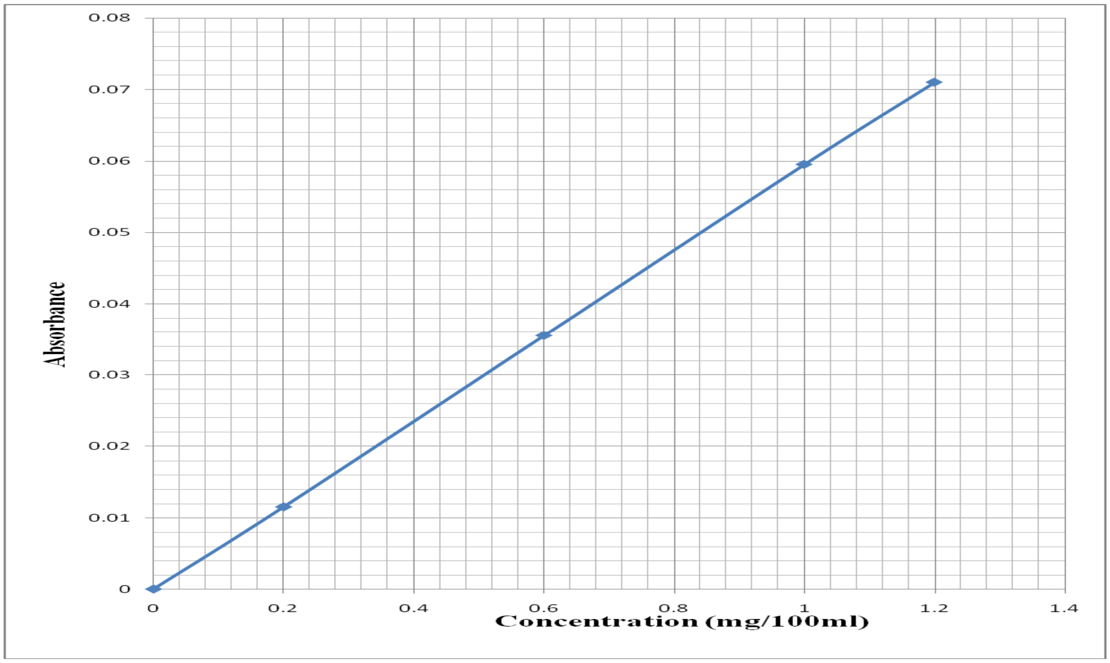

Fig. 2. Calibration curve of disperse blue 1 dye in TCM at 605 nm

Table 3 showed the results of the effects of heat treatment on the concentration of the extracted dye in PCE and TCE at 20°C, 30°C and 50°C as extrapolated from Figs. 1 and 2. The temperature range used for this work was below the boiling points for PCE (121°C) and TCM (76.7°C) to avoid solvent evaporation. From our findings, heating the extracted dye solution in TCM at 20°C and 30°C did not show any significant reduction in concentration spectrophotometrically except at 50°C where a little reduction of 0.2% was noticed. However, the extracted dye was found to be unstable in PCE at the various treatment temperatures with 0.7% (20°C), 1.0% (30°C) and 1.4% (50°C) reduction in concentration which implies that the dye got broken down in PCE more easily.

Polyester fabrics obtained after the dye extraction process were subjected to tensile strength testing in terms of elongation at break and work of rupture to determine whether the dye extraction process using the two solvents will have adverse effects on it or otherwise.

Generally, from Table 4, the values obtained for the two parameters relative to the extraction time in PCE and TCM showed similar trends of 600 s > 300 s > 150 s. The values obtained for the elongation at break and work of rupture of the extracted samples was close to the values recorded for the untreated and the dyed fabrics. This is an indication that the fabric retains their strength and toughness property after the removal of dye from its surface. The initial solvent pretreatment of the polyester fibre before the dyeing may have provided the overriding effects that resulted in the observed greater resistance to further extension of the fabrics during the extraction period [10].

Table 3. Thermal stability of the extracted dye at different temperature

Sample	Solvent	Temp (°C)	Initial concentration (mg/g)	Final concentration (mg/g)	Reduction in concentration (%)
Extracted dye (600 s)	PCE	20	29.4	29.2	0.7
	TCM		51.2	51.2	0.0
Extracted dye (600 s)	PCE	30	29.4	29.1	1.0
	TCM		51.2	51.2	0.0
Extracted dye (600 s)	PCE	50	29.4	29.0	1.4
	TCM		51.2	51.1	0.2

Table 4. Tensile strength determination of the polyester fabric after dye extraction

Treatment	Solvent	Work of rupture (gf.cm)	Elongation at break (%)
Raw fibre	-	6854.15	120.40
Dyed fabric	-	6876.20	138.16
Tensile strength of fabric after 150 s dye extraction	PCE	6861.28	131.42
	TCM	6859.19	130.65
Tensile strength of fabric after 300 s dye extraction	PCM	6872.52	132.56
	TCM	6869.47	133.60
Tensile strength of fabric after 600 s dye extraction	PCE	6873.38	130.86
	TCM	6870.46	135.10

3.2 Structures of Polyester Fabric after Dye Extraction

In addition to the stability observed for the fabrics after dye extraction in terms of elongation at break and work of rupture discussed above, the stability of the structures of the polyester fabrics after the dye extraction in chlorinated solvents including PCE and TCM using scanning electron micrograph (SEM) and X ray diffractometry (XRD) have also been reported [11].

4. CONCLUSION

The results from this work showed the stability of extracted dye from the surface of polyester fabric to diffused light and changes in temperature. Our work established the stability of the extracted dye in TCM and suggests that it would be a better solvent to maintain the aesthetic nature of dyed fabrics during dry cleaning especially at these verified temperatures (20°C and 30°C). The outcome of this work will be of importance to handlers of dyed polyester fabrics in choosing appropriate non aqueous solvent that will prolong the aesthetic properties of fabrics during dry cleaning. The information obtained will also classify TCM as a useful chemical for reduction clearing and leveling of unevenly dyed fabrics where reuse of extracted dyes and solvents may be required to make solvent dyeing economical.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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