International Journal of Home Science

ISSN: 2395-7476
IJHS 2017; 3(2): 770-778

www.homesciencejournal.com
Received: 20-03-2017
Accepted: 21-04-2017

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Sericin based VUV irradiated polyester dyeable with disperse dyes

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Abstract
Polyester (PET) fiber has acquired a major position in textile and apparel trade across the world due to its excellent physicochemical properties, good mechanical strength combined with its resistance to chemicals and abrasion, stretching, shrinking, and wrinkling. However because of its non-polar and hydrophobic nature, it is difficult to apply any finish directly on it. In an effort to apply sericin finish on PET and enhance its multifunctional properties and dyeability, in the present study, low environment technology of VUV excimer has been explored. The results show that irradiation treatment aided in lowering the dyeing temperature of polyester from 130 ºC to 100 ºC. Maximum dye uptake was observed at much shorter duration of treatment i.e. 60min. Irradiation treatment also aided in application of sericin, a natural biopolymer on non-polar PET surface. Sericin further enhanced the dyeability with the moisture regain (MR) and radical scavenging activity (RSA) of PET. No improvement in antimicrobial properties was seen. Sericin finish applied was observed to be durable. The color fastness properties of the dyed sericin treated fabrics was found excellent.

Keywords: Polyester, VUV excimer lamp, disperse dye, surface modification, moisture regain, radical scavenging activity

Introduction
The term ‘disperse dye’ has been applied to the organic colouring substances which are free from ionizing groups and are suitable for dyeing hydrophobic fibres. Disperse dyes have substantivity for one or more hydrophobic fibres e.g. cellulose acetate, nylon, polyester, acrylic and other synthetic fibres. A feature of disperse dye molecules is their lack of polar groups, evidenced by their insolubility in water. The dyeing of hydrophobic fibres like polyester with disperse dyes may be considered as a process of dye transfer from liquid solvent (water) to a solid organic solvent (fibre).Disperse dyes are added to water with a dispersing agent to form an aqueous dispersion. The insolubility of disperse dyes enables them to leave the dye liquor as they are more substantive to the organic fibre than to the inorganic dye liquor. The application of heat to the dye liquor increases the energy of dye molecules and accelerates the dyeing of textile fibres. Heating of dye liquor swells the fibre to some extent and assists the dye to penetrate the fibre polymer system. Thus the dye molecule takes its place in the amorphous regions of the fibre. Once taking place within the fibre polymer system, the dye molecules are held by hydrogen bonds and van der waals’ force (Bhatti, Adeel, Parveen & Zuber, 2013) [2].

High crystallinity, hydrophobic nature, compact molecular structure and lack of any reactive site in polyester renders it a difficult to dye fiber. High temperatures are particularly useful for dyeing polyester fibres. Disperse dyes can sublime into polyester fibers by heat through thermosol and/or thermofixation processes as well as can be applied with high temperature/pressure (around 130 °C) or via carriers at boiling temperature by an exhaust process. These methods result in swelling up of the polyester fiber polymer with aid of high temperature or carriers which assist in the entry of dye molecules inside the fiber polymer system. However, these energy extensive techniques of HTHP and the poisoning effect of carriers necessitated the need to find out other cheap and adequate dyeing methods (Gendy & Ali, 2007) [6].

Apart from the conventional dyeing methods, various studies have been reported on dyeing Polyester without use of carriers at boiling temperature after giving them a pre modification

Treatment with alkali, ultrasonic or gamma rays. Needles, Holmes & Park (1990) [14] examined and compared the dyeing characteristics and resultant colour properties of alkali modified and untreated polyester using six different disperse dyes. Deeper depth of shades was observed in case of alkali modified samples with a slight difference in shade at 100 °C. Dye structure and molecular size were observed to be affecting the amount of dyes absorbed by the fibres. Similar effect of dye molecular weight has been reported by Fite, 1995 [4]. Xu and Liu (2003) [18] reported an improvement in dye-uptake ratio after pretreatment of polyester fabrics with corona discharge irradiation. Gendy (2004) [5] explored the technique of grafting to enhance disperse dye uptake of polyester. The efficiency of disperse red dye uptake was found to increase on grafting of polyester with acrylic acid comonomer. In another study, Kamel, Zawahry, Helmy & Eid (2011) [11] worked on disperse dyeing of polyester using an atmospheric pressure dielectric barrier discharge (APDBD) pretreatment. The results revealed the efficiency of the oxygen plasma treatment in lowering the dyeing temperature of polyester fabrics from 130 °C, in the case of untreated polyester fabrics, to 100 °C. Additionally, the color fastness properties of the oxygen plasma-treated fabrics were found to be excellent and similar to those of the untreated fabric (Bhatti, Adeel, Parveen & Zuber, 2013 [2]

Researchers have also explored various alternatives to solve the problem of dyeing polyester fibers by application of biopolymers on fiber surface while imparting it additional properties. Manyukova & Safonov, 2009 [13] established experimentally that the treatment with chitosan on PET decreases the duration and temperature of dyeing while increasing its colour intensity and sorption properties. Walawaska, Filipowska & Rybicki, 2003 [16] reported an enhanced colour strength of the alkali modified chitosan deposited samples on dyeing with direct dyes. Unlike chitosan, sericin biopolymer has not been fully explored.

Sericin, a natural biopolymer can be used to impart properties like antibiotic-antibacterial activity, UV resistance, oxidative resistance and moisture absorption ability to fiber surface. It is made of 18 amino acids containing various type of side groups such as amino, carboxyl and hydroxy groups. In terms of the polarity of the amino acids there are 42.3% polar amino acid and 12.2% of non-polar amino acid (Padamwar & Pawar, 2004) [15]. Chemical approaches based on grafting and crosslinking have been used to fix a protein macromolecule such as sericin on polyester (Gupta, Chaudhary & Gupta, 2014; Kongdee, Okubayashi, Tabata & Hori, 2007) [9, 10, 12]. However, limited work has been done on the use of UV radiation treatment or application of a sericin for improving the dyeing behavior of polyester with disperse dyes and its other performance properties.

Materials and methods

Materials

Plain weave polyester fabric with 90g per square meter weight and 55 ends/ cm; 33 picks/ cm was used for the study. A Xenon Excimer UV lamp (XERADEX 20W/L40/120/SBSX46/KF50) emitting monochromatic light in the VUV region (172 nm), supplied by Messrs Radium Lampenwerk Wipperfurth, Germany, power supply (DBD 110 V/230 V 50 Hz/60 Hz) was used for pretreatment of polyester fabric.

Raw silk waste procured from Central Silk Technology Research Institute, Central Silk Board, and Bangalore, India was used as the source of sericin. Sericin was extracted in deionized water by treating raw silk waste for 40 min at 100^0C at a material-to-liquor ratio of 1:20 as per the method developed earlier (Gupta *et al*. 2013) [8]. Structure of disperse dyes used in the studyis given in Figure 1.Infrared dyeing machine DLS 7000 (Daelim Scarlet, Korea) was used for the extraction of sericin.

Treated polyester samples were dyed with 2 disperse dyes i.e. For on Yellow SE-3GL (C.I. Disperse Yellow 64) procured from Colour Chem Ltd., India and Disperse Navy Blue S-2GL(C. I. Disperse Blue 79) received from Sanchi chemicals Pvt. Ltd., India. Dyeing was carried out using IR dyeing machine (DLS 7000, Daelim Scarlet, Korea).

Reagent grade glutaraldehyde (Merck), magnesium chloride (Merck) and acetic acid (Merck) were used. Analytical grade sodium carbonate (Qualigen), sodium hydroxide (Qualigen), copper sulphate (Merck), sodium potassium tartarate (Merck), bovine serum albumin (Spectrochem), folin ciocalteau's phenol reagent (Merck) were used. Dispersing agent, setamol WS procured from BASF Textile chemicals was used. Deionized water was used for all experiments. Lissapol N (a commercial product) was used as the non-ionic surfactant for scouring.

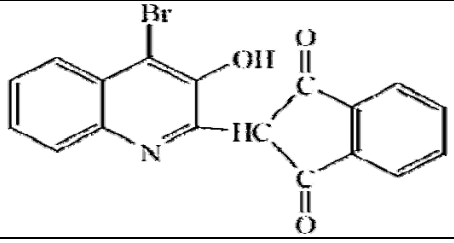
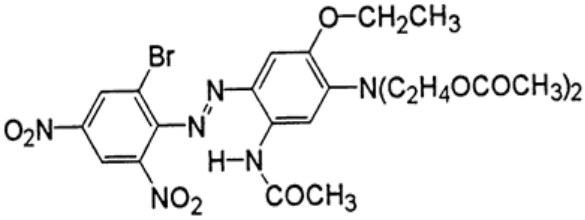
S. No.	Dye name	Structure
1.	Foron Yellow SE-3GL (C.I. Disperse Yellow 64)	
2.	Disperse Navy Blue S-2GL (C. I. Disperse Blue 79)	

Fig 1: Structure of disperse dyes used in the study

Method

Pretreatment of Polyester with UV

Polyester fabric was scoured thoroughly using lissapol N to remove any sort of temporary surface finish. Samples were dried and conditioned before use.

Samples were exposed to UV light under atmospheric conditions for surface modification. Treatment was carried out on both sides for 15 min keeping 5 mm distance from the lamp (Gupta, Chaudhary & Gupta, 2014a) [9, 10].

Application of sericin on irradiated samples

The quantity of protein in the extracted liquor was calculated by Lowry's method using bovine serum albumin (BSA) as a standard. PET fibre being non-polar and inert in nature does not have affinity towards sericin. Glutaraldehyde (GTA) was used as a crosslinking agent to bind sericin to excimer modified polyester. Irradiated fabric samples were padded with 10mL/L of GTA and 10g/L of sericin solution (80% expression) in a laboratory padding mangle by a 2-dip/2-nip process. After padding, the fabric was dried at 80 ^{0}C for 3min and cured at 130 ^{0}C for 2min. Cured samples were washed, dried and conditioned.

Dyeing with disperse dyes

Dyeing cycle: Dyeing cycle used in the study is shown in Figure 2 and the process variables studied are shown in Table 1. Dye was solubilised with 1g/L dispersing agent. pH of the dye bath was adjusted to 5 by acetic acid. Polyester fabric was introduced into the dye bath at 50 ^{0}C. After 10 min, temperature was increased to 70 ^{0}C at a rate of 2 ^{0}C/min. After 5 min at 70 ^{0}C, temperature was increased to maximum dyeing temperature at the rate of 1 ^{o}C/min. Dyeing was continued for the time durationand dyeing temperature as mentioned in Table 1. Subsequently, the dye bath temperature was decreased to 60 ^{o}C and the fabric samples removed from the bath. They were rinsed with cold and then hot water. Samples were finally soaped with 2g/L of Lissapol N at 70 ^{o}C for 10 min, rinsed and left to dry at room temperature.

Excimer modified samples were initially dyed with disperse dyes to establish the optimum conditions of dyeing. Further, samples irradiated with UV and then treated with sericin were dyed using the optimum conditions.

Table 1: Variables used for dyeing PET with disperse dyes

Parameter	Values
Time (min)	30,60, 90
Temperature (°C)	90, 100, 120, 130
Liquor ratio (LR)	1:30
Dye concentration (%)	0.25, 0.5, 1, 2, 3

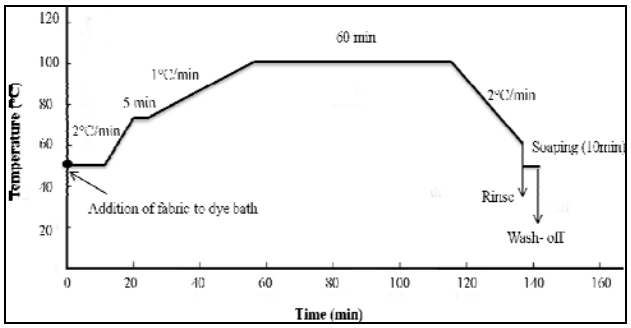


Fig 2: Dyeing cycle for disperse dyes

Testing of dyed and sericin treated samples

The dye uptake and other multifunctional properties were tested for the sericin treated and samples dyed after sericin application. Fabric samples were conditioned for 24hrs in an atmosphere maintained at 65 ±2% relative humidity at 27 °C before testing.

Colour value measurement

The relative color strength (K/S) was measured using Color-Eye 7000A computer colour matching system (Gretag Macbeth, USA).The K/S values were established according to the Kubelka Munk equation-

$$K/S = \frac{(1-R)^2}{2R} \quad \text{.....Eq (1)}$$

Where K and S stand for the absorption and scattering coefficients respectively, and *R* stands for the reflectance value. To evaluate the colour parameters of the disperse dyed samples, CIE Lab system is used, where L* refers to lightness–darkness values from 100 to 0 representing white to black, a* values run from negative (green) to positive (red) and b* values run from negative (blue) to positive (yellow).

Weight loss

Weight loss was determined by measuring the difference in weight of the samples before and after dyeing. The weight loss (WL) is expressed as relative WL according to the equation,

$$\text{Weightloss (\%)} = \frac{(W1-W2)}{W1} X\ 100 \quad \text{……Eq(2)}$$

Where w_1 and w_2 are the weights of the samples before and after dyeing treatments.

Moisture regain

Moisture regain was measured in using ASTM D629-99 standard by comparing the dry weight and moisture conditioning weight of polyester fabrics. Samples were dried in an oven at 105^{0}C for 1h and then weighed after cooling in a desiccator for 30 min. Moisture conditioning was carried out at 20^{0}C and 65 % relative humidity for 24h. The moisture regain was calculated using the following equation:

$$\text{Moisture regain (\%)} = \frac{Wm - Wd}{Wd} X\ 100 \quad \text{.....Eq (3)}$$

where, w_m is the weight of fabric in moisture equilibrium state at 20^{0}C and 65 % relative humidity, and w_d is weight of fabric dried at 105^{0}C for 1h.

Radical scavenging activity

Free radical scavenging potential of an antioxidant compound or extract can be assessed using DPPH (2, 2-diphenyl-1-picrylhydrazyl) assay. Below mentioned equation was used for the calculation of free radical scavenging activity,

$$\text{Scavenging activity (\%)} = 1 - \frac{OD\text{sample}}{OD\ \text{blind}} X\ 100 \quad \text{..... Eq (4)}$$

Where scavenging activity refers to the free radical scavenging percentages, OD sample refers to the absorbance of the sericin treated sample, OD blind refers to the absorbance of the blind control.

Antimicrobial activity

Qualitative assessment (Disc Diffusion Method): Disc diffusion method according to AATCC 147 standard was used for assessing the bacteriostatic activity of sericin finished samples.

Wash fastness

The colour fastness to washing was determined according to the AATCC test method 61–1075 using a Laundrometer (R. B. Electronic and Engineering Private Limited, India). The

change in colour of the treated test specimens and the degree of staining of the two adjacent undyed fabrics was evaluated and rated using grey scales.

Results and Discussion

PET samples were irradiated with UV excimer and then dyed with two disperse dyes using variable conditions. Results are discussed below.

Effect of temperature of dyeing

It can be seen from the Figure 3, that in case of both dyes, the colour value is higher for excimer modified samples, with respect to control polyester. It can also be observed that in exposed samples the saturation value is higher, i.e. 6.72 vs 6.19 and 2.56 vs 1.72 for both dyes. Additionally, the saturation value is attained at a lower temperature i.e. 100^0C in irradiated PET as compared to untreated PET indicating complete exhaustion of dye in excimer modified samples at 100 °C. Similar results have been reported by Bhatti, Adeel, Parveen & Zuber, 2013 [2], where treatment with UV radiation of 254nm, resulted in maximum colour strength at 100^0C.

Effect of dyeing time

K/S of irradiated samples was observed to be higher than control samples at various intervals of time. On increasing the dyeing time from 30-120min, maximum value of K/S was observed in irradiated sample at 60 min, beyond which no change was observed. The trend observed in both dyes was same. Results are shown in Figure 4.

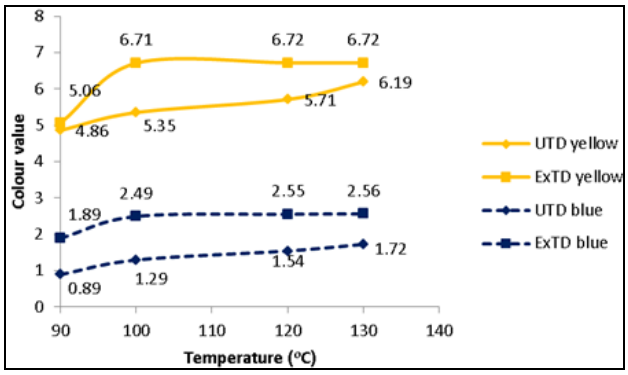


Fig 3: Effect of temperature on colour strength of disperse dyed samples (0.5% shade, 60min) (UTD- Control+ dye; ExTD- Excimer treated+ dye)

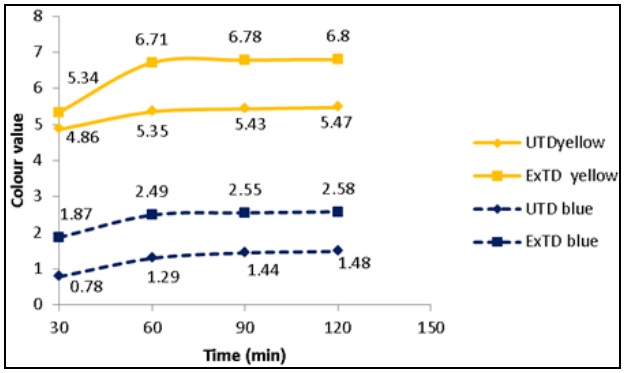


Fig 4: Effect of time on colour strength of disperse dyed samples (0.5% shade, 100 °C) (UTD- Control+ dye; ExTD- Excimer treated+ dye)

Effect of concentration of dyebath

Results show (Figure 5) that in both control and irradiated samples, maximum amount of dye uptake is at 2%. Higher amount dye uptake at all the dye concentrations was obtained in the case of the excimer modified samples as compared to control samples. At lower dye concentration (0.25, 0.5%), the difference between irradiated and control samples was observed to be lesser, in comparison to higher dye concentrations (1, 2, 3%). Thus, it can be inferred that deeper shades can be produced with same amount of dye using pretreatment with excimer lamp. The trend observed was same in both the dyes, with higher value of K/S of disperse yellow dyed samples.

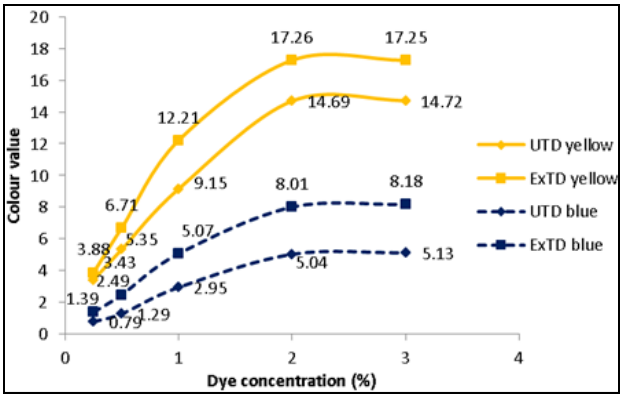


Fig 5: Effect of dye concentration on colour strength of disperse dyed samples (100 °C, 60 min) (UTD- Control+ dye; ExTD- Excimer treated+ dye)

Results show that the dye uptake of polyester after pre-modification treatment increases considerably in comparison to control. Irradiation by VUV excimer lamps at 172 nm results in formation of free radicals on the fabric surface due to breakage of C=C bond by high energy photon (7.2eV).The diffused or ambient oxygen reacts quickly with these free radicals producing oxidized structures within the polymer, such as ketone, carboxylic acid and alcohol functionalities as well as peroxide species. Another phenomenon occurring at the same time is ozone-oxygen cycle. Strong absorption of 172 nm radiation by atmospheric gases like oxygen, carbon dioxide and water vapor results in formation of oxygen containing polar entities such as hydroxyl and carboxyl groups responsible for increased polarity on polyester surface (Gupta, Siddhan & Banerjee,2007) [7].

Thus, on the basis of the above studies, the process conditions for dyeing of irradiated polyester with disperse dyes were observed to be 100 °C, 60 min. Maximum depth of colour was observed at 2% of dye concentration.

Application of sericin on irradiated polyester

Sericin was applied on modified polyester samples using GTA as crosslinking agent. GTA has two aldehyde groups, and can thus react with two different chemical groups simultaneously enhancing the attachment of sericin on modified polyester. One aldehyde group of GTA reacts with alcohol group of modified polyester to give a hemiacetal. This hemiacetal, having another aldehyde group on the other end, can further react with the amino groups of sericin, thus resulting in its fixation over polyester surface (Gupta, Chaudhary & Gupta, 2014) [9, 10].

Dyeing of sericin treated polyester samples

Sericin treated samples were dyed with disperse dyes using the process conditions established for dyeing of irradiated polyester i.e. at 100 °C for 60 min. Schematic representation

of dyeing of sericin treated polyester fabric with disperse dyes is given in Figure 6.

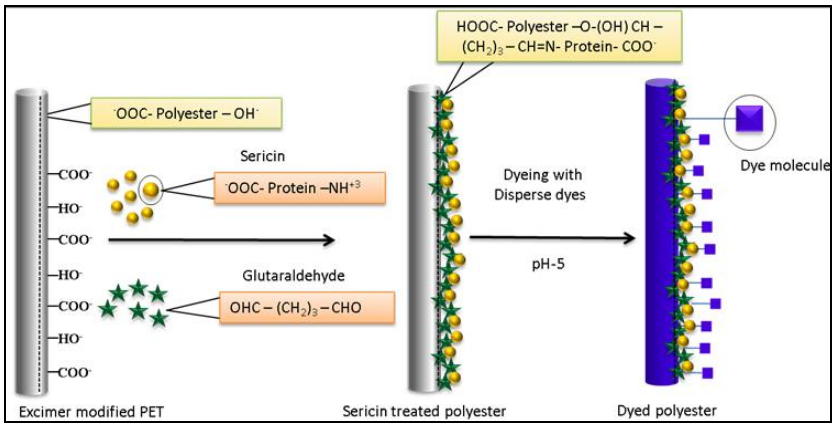


Fig 6: Schematic representation of dyeing of sericin treated polyester fabric

The dye uptake of control samples was found to increase from 3.43 to 14.69 for disperse yellow dyed samples and from 0.79 to 5.04 for disperse navy blue samples, with increase in dye level from 0.25 to 2%. Colour values of ExTD samples were found to be higher than UT samples. However, maximum dye uptake was seen in Ex TSD samples. With increase in disperse yellow dye concentration from 0.25-2%, colour value of Ex TSD samples was observed to increase by 55, 52, 61 and 35%. Similar trend was observed in disperse navy blue dyed samples, with more than 100% increase in colour value of Ex TSD samples at 0.25, 0.5% concentration and ~90-95% increase in samples dyed with 1-2% shade (Figure 7,8).

	Dye Concentration			
Samples	**0.25%**	**0.5%**	**1%**	**2%**
UTD				
ExTD				
ExTSD				

Fig 7: Shade card showing polyester samples dyed with disperse yellow (UTD- Control+dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

	Dye Concentration			
Samples	**0.25%**	**0.5%**	**1%**	**2%**
UTD				

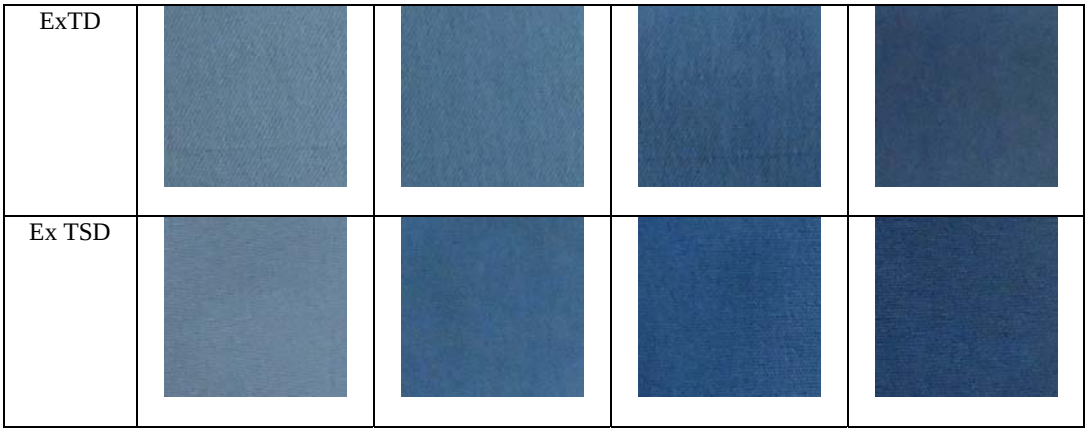


Fig 8: Shade card showing polyester samples dyed with disperse navy blue (UTD- Control dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

L* values of Ex TSD samples were also observed to be lower than all the UTD and ExTD samples dyed at similar concentration, indicating higher depth of shade in comparison to others. +a* value of disperse yellow Ex TSD samples was found to increase on sericin application indicating an increase in redness character of fabric samples. In addition, the Ex TSD fabrics were observed to be bright yellow, which could be appreciated by their highest + b* values (Table 2). –b* value of disperse navy blue dyed Ex TSD samples increased indicating an increase in blueness of the fabric (Table 3).

Table 2: Colorimetric data of polyester dyed with varying concentrations of disperse yellow

Dye concentration (%)	Sample code	K/S	L*	a*	b*	C*	h°
0.25	UTD	3.43	77.61	-0.19	36.99	36.99	90.29
	ExTD	3.88	76.07	-0.04	37.03	37.03	90.07
	Ex TSD	5.33	74.07	1.95	41.06	41.11	87.28
0.50	UTD	5.35	75.6	2.12	42.63	42.68	87.15
	ExTD	6.713	74.03	3.9	46.66	46.83	85.22
	Ex TSD	8.17	71.81	4.8	47.86	46.83	85.22
1.00	UTD	9.15	71.54	8.67	51.26	51.99	80.4
	ExTD	12.21	70.23	11.25	56.98	58.08	78.83
	Ex TSD	14.74	68.04	13.51	59.11	60.63	77.13
2.00	UTD	14.69	67.15	16.03	59.53	61.65	74.92
	ExTD	17.262	66.04	19.48	64.32	67.2	73.15
	Ex TSD	19.93	64.43	21.45	65.97	69.36	71.99

(UT- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

Table 3: Colorimetric data of polyester dyed with varying concentrations of disperse navy blue

Dye concentration (%)	Sample code	K/S	L*	a*	b*	C*	h°
0.25	UTD	0.79	68.83	-3.33	-18.15	18.45	259.60
	ExTD	1.39	62.03	-6.99	-17.5	18.84	248.22
	Ex TSD	1.64	59.51	-7.23	-16.71	18.2	246.59
0.50	UTD	1.29	62.99	-4.45	-20.60	21.07	257.81
	ExTD	2.49	54.69	-7.25	-20.98	22.2	250.94
	Ex TSD	2.91	52.35	-7.53	-20.39	21.74	249.73
1.00	UTD	2.95	56.06	-5.49	-21.88	22.56	255.91
	ExTD	5.07	45.22	-6.58	-24.55	25.41	255
	Ex TSD	5.71	43.44	-6.85	-23.42	24.41	253.71
2.00	UTD	5.04	45.40	-6.59	-24.18	25.07	254.76
	ExTD	8.01	38.34	-4.55	-25.74	26.14	259.98
	Ex TSD	9.17	36.64	-4.94	-24.79	25.28	258.72

(UTD- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

On the basis of the results it can be inferred that, the colour uptake of control samples was found to be the least. Post irradiation, disperse dye uptake was observed to increase. However, sericin treatment on irradiated samples further enhanced the dye uptake. This may be due to presence of polar groups in sericin which bind to the disperse dyes with the help of ionic linkages, resulting in higher dye uptake

Wash fastness

Durability of fabrics to washing is one of the major concerns of textile researchers and users because textiles are subjected to frequent laundering. Disperse dyed control, irradiated and sericin treated samples were tested for their fastness to fading and staining. The colour fastness ratings of the dyed fabrics are given in Table 4 (a, b). Wash fastness values for staining and fading of samples dyed with disperse yellow and navy blue were observed to be very good (4/5-5).properties. Good colour fastness properties are observed due to presence of benzene rings in disperse dye molecules that show more affinity towards irradiated fabric and resistance towards

agencies such as detergent, heat, light and rubbing (Adeel *et al*. 2012) [1].

Trend observed was similar for both yellow and navy blue disperse dyes, with disperse yellow showing higher affinity towards PET. Thus, for further analysis only samples dyed with disperse yellow were considered.

Table 4 (a): Wash fastness ratings for samples dyed with disperse yellow

Sample code	Wash fastness							
	Change in colour				Staining (Cotton and wool)			
	0.25%	0.5%	1%	2%	0.25%	0.5%	1%	2%
UTD	5	5	5	5	5	5	5	5
ExTD	5	5	5	5	5	5	4/5-5	4/5-5
Ex TSD	5	5	5	5	5	5	5	5

(UTD- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

Table 4 (b): Wash fastness ratings for samples dyed with disperse navy blue

Sample code	Wash fastness							
	Change in colour				Staining (Cotton and wool)			
	0.25%	0.5%	1%	2%	0.25%	0.5%	1%	2%
UTD	5	5	5	5	5	5	5	5
ExTD	5	5	4/5	4/5-5	5	5	4/5-5	4/5-5
Ex TSD	5	5	4/5	4/5	5	5	4/5	4/5

(UTD- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

Testing of dyed and sericin treated samples

Weight loss

Samples treated with sericin post irradiation showed a weight add on of around 1.42%. After dyeing with disperse dyes, no decrease in weight was observed; indicating that the finish applied is durable and does not leach out in dye bath.

Moisture regain

Moisture regain (MR) values of control PET dyed with disperse yellow (UTD samples) was observed to be same as undyed PET i.e. 0.60 ± 0.10%, indicating no effect of dye on MR values of control PET. On irradiation, the MR values were found to increase to 1.2 ± 0.05 due to generation of polar groups on the surface of the fiber. Furthermore, sericin application was found to enhance the MR values to 2.30 ± 0.05. Sericin is composed of 80% amino acids that contain hydrophilic groups such as serine, aspartate and glycine which result in good moisture regain (Padamwar & Pawar, 2004) [15]. The results are shown in Table 5. It can be seen from the results that the MR values of ExTD and Ex TSD samples do not change with increase in dye concentration from 0.25 to 2% shade.

Table 5 (a): Rub fastness ratings for samples dyed with disperse yellow

Sample code	Rub fastness (Dry)								Rub fastness (Wet)							
	Change in colour				Staining				Change in colour				Staining			
(%)	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2
UTD	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
ExTD	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4/5-5	4/5-5
Ex TSD	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4/5-5	4/5-5

(UTD- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

Table 5 (b): Rub fastness ratings for samples dyed with disperse navy blue

Sample code	Rub fastness (Dry)								Rub fastness (Wet)							
	Change in colour				Staining				Change in colour				Staining			
(%)	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2
UTD	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4/5-5
ExTD	5	5	5	5	5	5	5	5	5	5	5	5	5	4/5-5	4/5-5	4/5-5
Ex TSD	5	5	5	5	5	5	5	5	5	5	5	5	4/5-5	4/5-5	4/5-5	4/5-5

(UTD- Control+ Dye; ExTD- Excimer treated+ dye; Ex TSD- Excimer treated+ sericin+ dye)

Radical scavenging activity

Disperse yellow dyed PET samples treated with sericin were evaluated for their radical scavenging activity (RSA). Results are shown in Table 6 and 7. No RSA was observed in UTD samples. RSA values of ExTD and Ex TSD samples were found to be more than control and irradiated samples. In case of ExTD samples, RSA values were observed to be around 16 ± 0.56 irrespective of the % dye level. An increase in RSA values from 16 ± 0.56 to 34.40 ± 1.40 was seen on application of sericin. Thus may be due to the fact that, silk sericin has functional groups like cysteine, tyrosine and histidine which contain electron donors. In addition, flavanoids (phenolics) present in sericin mainly due to their redox properties act as reducing agents or hydrogen atom donors. These donors react with free radicals and convert them to more stable products and terminate the radical chain reaction (Fan *et al*., 2009). RSA values were same for all Ex TSD samples dyed with 0.25 to 2% shade.

Table 6: Moisture regain of samples dyed with disperse yellow dye

Dye concentration (%)	Moisture regain (%)		
	UTD	ExTD	Ex TSD
0.25	0.60 ± 0.10	1.24 ± 0.04	2.30 ± 0.05
0.5	0.60 ± 0.06	1.22 ± 0.02	2.33 ± 0.03
1	0.60 ± 0.03	1.28 ± 0.02	2.34 ± 0.02
2	0.60 ± 0.10	1.2 ± 0.05	2.30 ± 0.05

(UT- Control+ Dye; Ex TSD- Excimer treated+ sericin+ dye; Ex TDS- Excimer treated+ dye+ sericin)

Table 7: Radical scavenging activity of samples dyed with disperse yellow

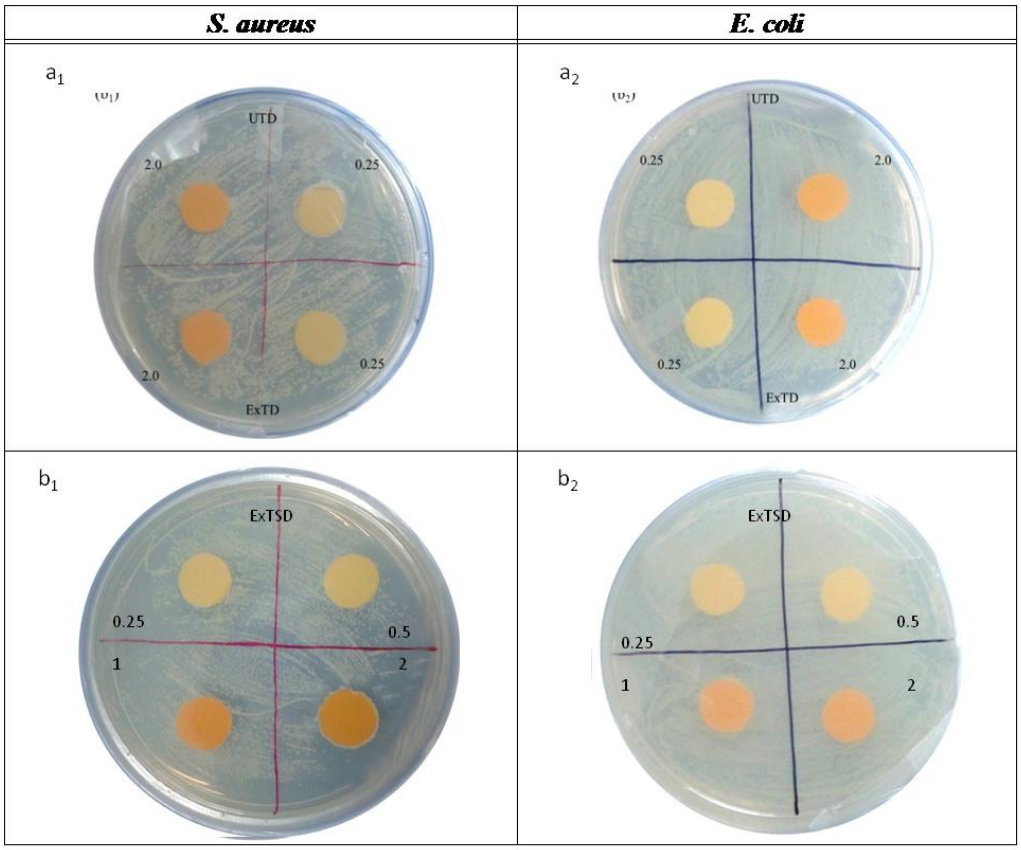
Dye concentration (%)	RSA activity (%)		
	UTD	ExTD	Ex TSD
0.25	0	15.56 ± 1.39	33.33 ± 2.06
0.5	0	15.32 ± 1.43	33.82 ± 1.24
1	0	15.66 ± 1.52	33.66 ± 1.84
2	0	16 ± 0.56	34.40 ± 1.40

(UTD- Control+ Dye; Ex TSD- Excimer treated+ sericin+ dye; Ex TDS- Excimer treated+ dye+ sericin)

Antimicrobial activity

Disc diffusion method was done for polyester samples with the objective to detect antibacterial activity of the dye and sericin component. The samples were tested against gram positive (*S. aureus*) and gram negative (*E. coli*) bacteria. Growth was observed on UTD, ExTD and Ex TSD samples (Figure 10) dyed with 0.25 and 2% dye concentration of disperse yellow dye indicating an absence of antibacterial activity against both *S. aureus* and *E. coli*.

Figure 10: Plates showing the antimicrobial results of disperse dyed polyester samples against *S. aureus* and *E. coli* ((a_1, a_2) UTD- Control+ dye, ExTD- Excimer treated +dye; (b_1, b_2) Ex TSD- Excimer treated+ sericin+ dye)



Conclusion

The results of this study show that VUV irradiation treatment can be used as an effective technique for surface modification of polyester fabrics. Irradiation treatment enhanced the disperse dye uptake of polyester samples while imparting deeper shades with same amount of dye as for untreated samples. It also aided in lowering the dyeing temperature of polyester from 130 °C in case of untreated fabrics, to 100 °C. Also, in case of irradiated fabrics no change in colour values beyond 60min was seen, as the fabric got saturated with the dye molecules, compared with untreated samples.

Irradiation treatment also aided in application of sericin finish using glutaraldehyde as crosslinking agent. Sericin further enhanced the disperse dye uptake of polyester due to presence of polar groups which aided in disperse dye uptake forming ionic linkages. The results revealed that the sericin treatment

was not only effective in enhancing dyeability of polyester but also imparted multifunctional properties such as moisture regain and radical scavenging activity to it. No effect on dye concentration was observed on moisture regain and radical scavenging activity values. The sericin finished applied on polyester was observed to be durable with no weight loss been observed post dyeing. Additionally, irradiated samples treated with sericin dyed with disperse dyes showed similar colourfastness properties to those of untreated and irradiated samples. This may be because of the fact that irradiation results in nano level restructuring without affecting the bulk properties of the fiber.

Based on the results, it can be concluded that surface irradiation proves to be a promising modification treatment for imparting multifunctional properties to polyester whilst enhancing its dyeability with disperse dyes at much lower dyeing temperatures and shorter dyeing time. Hence, reducing the energy consumption and enhancing environmental protection.

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