



A novel green approach for dyeing polyester using glycerine based eutectic solvent as a dyeing medium



Sushant S. Pawar, Saptarshi Maiti, Santosh Biranje, Kedar Kulkarni, Ravindra V. Adivarekar*

Department of Fibres and Textile Processing Technology, Institute of Chemical Technology, India

ARTICLE INFO

Keywords:

Materials chemistry
Physical chemistry
Environmental science

ABSTRACT

In the past decade, water scarcity has become major concern and is going to be reality in future too. At the same time textile is necessity which needs a billion liters of fresh water for its processing. Out of this 16 % of water is only used for dyeing of textile materials. In a quest to develop a sustainable approach to reduce water scarcity, an attempt has been made to minimize water consumption in textile wet processing. In this work, an eco-friendly glycerine based eutectic solvent (GES) was prepared by using choline chloride, urea and glycerin to reduce water consumption in polyester dyeing. The prepared solvent was characterized in terms of FTIR. Dyeing parameters like time, temperature and pH were optimized for dyeing of polyester using GES as a dyeing medium. The efficacy of dyeing was analyzed by colour strength and colour performance properties; sublimation, wash and light fastness. In comparison with conventional dyed polyester overall dyeing performance was found to be better without affecting tensile strength of polyester which remains almost same whereas thermal stability of solvent dyed polyester was slightly improved compared with aqueous dyed polyester. The results obtained from this study suggest that the GES as a polyester dyeing medium can be a green approach in dyeing of polyester.

1. Introduction

Large consumption of water and hazardous effluent are two major challenges for development of sustainable textile industry. According to world bank, the conventional textile dyeing utilizes 5.8 trillion litres of water per annum which further contributes to the one fifth of world industrial water pollution leading to increase in environment pollution load (Blackburn, 2015; Kant, 2012). Textile industry is one of the highest consumers of water in the world. Diving into the pool of sustainability, a minimal consumption of water in the textile processing sector with an eco-friendly approach needs to be developed (Chen et al., 2017). Nearly 30–50 litres of water/kg of textile are required for dyeing depending upon the type of dyes used. In synthetic fibres, polyester production is hitting top position in the world and the demand of it is increasing day by day (Glynis, 2015; Kant, 2012). In recent years, the researchers are working on development of sustainable dyeing techniques such as supercritical carbon dioxide, air-dye, and plasma processing etc. in order to reduce water consumption in textile industry. During dyeing of polyester using supercritical carbon dioxide as a dyeing medium, trimer is produced which can be removed with the help of water only. Also, it is a batch process and requires initial high

investment. Solvent dyeing could be an alternative to water. It is one of the oldest techniques to minimize water requirement in textile industry. Chlorinated hydrocarbons like trichloroethylene, tetrachloroethylene (perchloroethylene) and 1,1,1-trichloroethylene were used as a solvent for dyeing of polyester (Gebert, 1971; Milicevic, 1967). Non-ionic surfactant based on reverse micelle system of Polyethylene glycol (PEG), n-octanol and alkane was used as a dyeing medium for electrolyte free dyeing of cotton with reactive dye to reduce water usage, materials and energy requirements and such dyeing showed comparable results with aqueous dyed cotton (Wang et al., 2016). Solvent assisted dyeing is another approach of dyeing to minimize water consumption. Low temperature solvent assisted dyeing of polyester fabric was done using micro emulsion of n-butylacetate. In this research work, small proportion of n-butyl acetate was used for preparation of micro emulsion to study kinetics of polyester dyeing using o-vanillin and coumarin as a dyeing auxiliary. Dye bath containing o-vanillin dyed polyester fabric showed better colour strength (K/S) than dye bath containing coumarin dyed polyester (Radei et al., 2018). 1–3 % Ethanol was used to increase dye exhaustion and substitute some auxiliaries such as wetting and leveling agent in dyeing of various yarns like wool, cotton, polyester, nylon and acrylic (Ferrero et al., 2011). Due to low volatility of ethanol,

* Corresponding author.

E-mail address: rv.adivarekar@ictmumbai.edu.in (R.V. Adivarekar).

glycerol was introduced in dyeing as an alternative to ethanol (Ferrero and Periolatto, 2012). Diffusion of reactive dye on aqueous NaOH preswollen mercerized cotton, viscose rayon and hollow viscose in alkali was investigated in acetone water mixture. Dyebath exhaustion and fixation on viscose rayon was found lesser than other fibres (Chavan and Subramanian, 1982). For the synthesis of ammonified ramie fabric ammonia gas and methanol was used as a reactant. Further dyeing of pre-treated ammonified ramie fabric was done using liquid ammonia as dyeing medium to improve dyeing efficiency (Peng et al., 2017). Dyeing of polyester was done using disperse dye in tetrachloroethylene by using cylindrical film roll method (Morita et al., 1975). Exhaust dyeing of polyester fabric was carried out in perchloroethylene with different auxiliaries at 120 °C for 30 minutes (Gebert, 1971). To reduce consumption of chemicals and water, liquid paraffin was preferred for the dyeing of polyester fabric (Xu et al., 2015).

Ionic liquid like 1-butyl-3-methylimidazolium chloride was employed in dyeing of wool to increase dye uptake (Yuan et al., 2010). For replacement of the dyeing auxiliary, ionic liquid 1-(2-hydroxyethyl)-3-methylimidazolium chloride was used in dyeing to increase colour strength of cotton, polyester and wool (Bianchini et al., 2015). Ionic liquids such as tributyl methylammonium methyl sulfate, tris (2-hydroxyethyl) methylammonium methyl sulfate, 1-ethyl-3-methylimidazolium diethyl phosphate, 1-ethyl-3-methylimidazolium ethyl sulfate, 1-ethyl-3-methylimidazolium acetate, and 1-ethyl-3-methylimidazolium chloride were used as a dyeing medium for the dyeing of polyester, polyester cotton blend and polyamide fibres (Opwis et al., 2013). Dyeing of polyester was carried out in the various 2-hydroxidiethanolamine based protic ionic liquids as a dyeing medium. Shortest chains protic ionic liquid dyed polyester shows better colour strength than other protic ionic liquids. Efficiency of protic ionic liquids as a dyeing medium for polyester dyeing was found to be good (Andrade et al., 2017). Various types of deep eutectic solvents (DES) were synthesized and employed in the processing of leather and it was found that DES helps non-ionic dyes to get absorbed on the leather (Abbott et al., 2006). DES is easily recoverable, non-toxic in nature and can be formed between quaternary ammonium salt and hydrogen bond donor (Dadrasnia and Ismail, 2015; Delgado-mellado et al., 2018; Kaur et al., 2018). Chlorinated solvents are well-known solvents for dyeing of polyester but being toxic they are banned so there is a dire need of an eco-friendly solvent which is readily available and also recyclable.

The present research work is mainly focused on to minimize consumption of water in textile dyeing using solvent dyeing technique. Glycerine based eutectic solvent (GES) was prepared using choline chloride, urea and glycerine to be used as dyeing medium to reduce water consumption and environmental hazards. The development of solvent dyeing techniques considering the demand for sustainable processes in the textile wet processing sectors in the last few decades has reached pre-high position. In view of such demand of greener technology and to rise a few steps higher to its standing position of sustainability, our approach to an application of novel and ecologically acceptable solvent (GES) has been made.

2. Materials and methods

2.1. Materials

Choline chloride extra pure, urea (AR), glycerine (AR), sodium hydroxide pellets (purified), glacial acetic acid (Extrapure) and sodium hydrosulfite (hydrose) were purchased from SD fine chemicals Ltd. Mumbai, India. Saragen KDF (leveling agent) was provided by Sarex chemicals Ltd., Mumbai, India. Disperse Blue 56 dye was supplied by Colorband dyestuff Pvt. Ltd., Mumbai, India. Polyester woven fabric was procured from Piyush syndicate, Mumbai, India with 70 GSM and 89 × 79 thread density.

2.2. Preparation of GES

For the preparation of GES, a mixture of choline chloride, urea and glycerine were taken in proportion of 1:1:1 (w/w). Glycerine based eutectic mixture was formed by continuous stirring for 15 min at 30 °C ± 2 °C in atmospheric pressure on magnetic stirrer at speed of 1200 rpm.

2.3. Characterization of GES in terms of FTIR

FTIR spectrum of GES was recorded using Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy having diamond/ZnSe crystal on FTIR 8400 Shimadzu spectrophotometer (Japan). Reflectance was measured in the range of 4000–650 cm⁻¹ by recording 45 number of scans.

2.4. Optimization of dyeing conditions

Dyeing of polyester fabric to be used as control (conventional method) was performed using Disperse Blue 56 as mentioned in the materials. Aqueous polyester dyeing was performed using following recipe.

% Shade	: 1 % dye (owf)
Leveling agent	: 3 % (owf)
Time	: 45 minutes
Liquor to goods ratio	: 20:1

Solvent dyeing of polyester fabric with 1 % Disperse Blue 56 was performed using GES as a dyeing medium without dispersing agent keeping liquor to goods ratio of 20:1 constant for all dyeings. Standard 1 % dye stock solution was prepared using 3 % leveling agent and 20 % acetic acid solution prepared in water. In optimized recipe, 80:20 (v/v) GES and water was used as a medium for dyeing of polyester with dye, 3 % leveling agent and 20 % acetic acid as dyeing auxiliaries. To study the effect of pH, solvent dyeing was carried out at 130 °C for 45 min at pH 1 to 9 and their respective pH was adjusted using dilute acetic acid and 0.5 M NaOH solution. For optimization of temperature, dyeing was performed in optimized pH at temperature range of 100–150 °C with an interval of 10 °C for 45 min. Similarly, for optimization of time, dyeing was performed at optimized temperature and pH for 15–60 min at an interval of 15 min. To study the effect of shade build up, dyeing was carried out at optimized time, temperature and pH with 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 % shades of disperse dye. All dyeings were performed in high temperature and high pressure (HTHP) beaker dyeing machine supplied by Rossari Labtech, Mumbai, India.

Reduction clearing treatment of all polyester dyed fabrics was carried out with 2 g/L hydrose and 2 g/L caustic soda at 70 °C for about 20 min followed by rinsing with cold water and further soaping with 2 g/L non-ionic soap (Auxipon NP).

2.5. Colour strength evaluation of dyed polyester fabric

Determination of colour strength of dyed polyester was carried out by K/S (Kubelka-Munk function) values using Spectra Scan 5100+ (Computer Colour Matching). K/S is calculated using following equation,

$$\frac{K}{S} = \frac{(1 - R)^2}{2R}$$

Where K stands for absorption coefficient, whereas S stands for scattering coefficient and R is the reflectance at complete opacity. In general, higher K/S values correspond to higher dye uptake on fabric.

2.6. Fastness testing of dyed polyester

Fastness testing of dyed polyester was evaluated using ISO methods. ISO 105-F04 method was used for the determination of sublimation

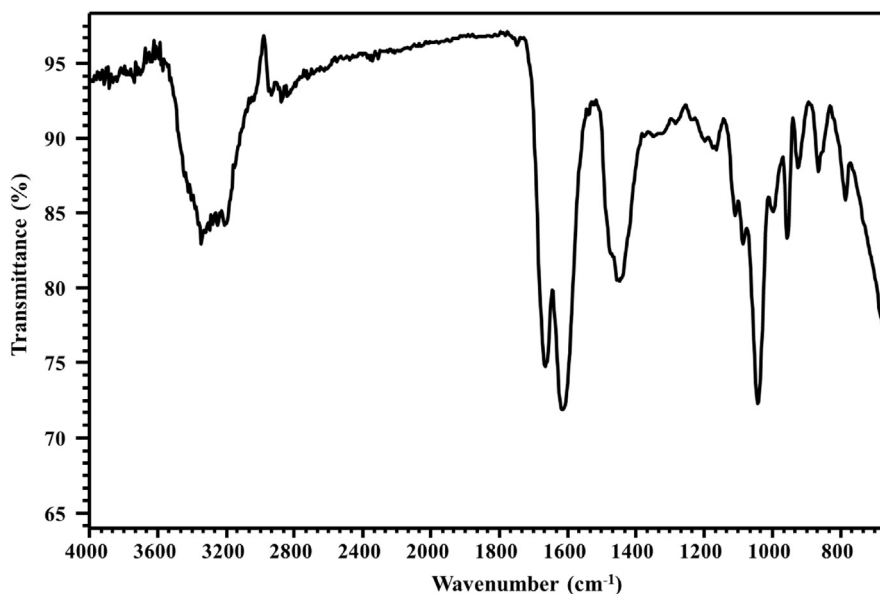


Fig. 1. FTIR spectrum of GES.

fastness on sublimation tester (RBE Electronics Egg. Pvt. Ltd., Mumbai, India). ISO 105-C03 method was carried out for the determination of colour fastness to washing of dyed polyester on launderometer (Rossari Labtech, Mumbai, India). ISO 105-B02 method was used for evaluation of colour fastness to light of dyed polyester on Q-Sun's Xenon Arc Light fastness tester.

2.7. Physical properties of polyester

2.7.1. Tensile properties

ASTM D 5035:1995 strip method was used for evaluation of tensile strength of polyester fabric. Measurement of tensile properties of undyed, aqueous dyed and solvent dyed polyester was carried out on H150KU-UTM tensile testing machine (USA).

2.7.2. Thermogravimetric analysis

Undyed, aqueous dyed and GES dyed polyester fabric were cut into small pieces and further thermogravimetric analysis (TGA) was performed in the range of 35–500 °C with a heating rate of 10 °C/min. Temperature and weighing accuracy of instrument were ± 0.3 °C and ± 1

% respectively. Static TGA of undyed, aqueous dyed and GES dyed polyester fabric were carried out at 100, 200, 300 and 400 °C for 2 hours hold time. Temperature accuracy for static TGA was ± 8 °C and rest parameters were same. Thermal analysis of polyester fabric was carried out on Shimadzu 60H DTG Japan instrument having weighing precision and sensitivity of 1 mg and 0.1 mg respectively.

Table 1

Functional groups of GES and their observed bands from FTIR spectrum.

Functional groups	Wave number range (cm ⁻¹)	Observed absorbance bands (cm ⁻¹)
Amide (-CONH ₂), N-H bending.	1510–1700	1616 & 1664
Carbonyl (C=O) derivatives	1510–1700	1616
Aliphatic chains of -CH ₂ and -CH ₃	1350–1470	1446
Hydroxyl (-OH), H-bonded	3200–3550	3330

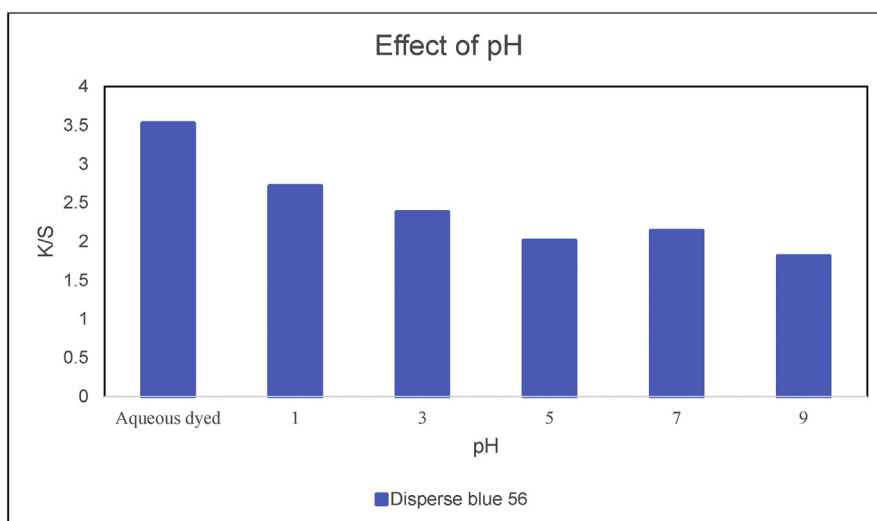


Fig. 2. Effect of variation of pH on colour strength of GES dyed polyester compared with aqueous dyed polyester.

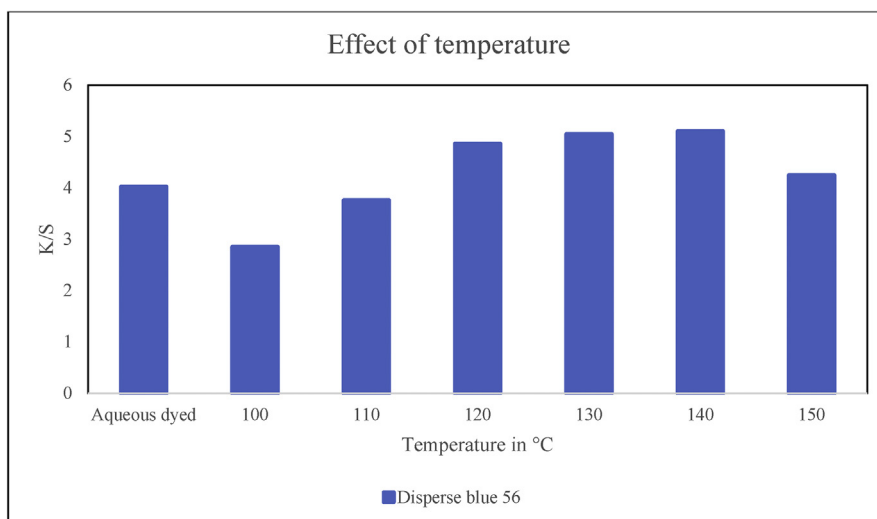


Fig. 3. Effect of variation of temperature on colour strength of GES dyed polyester compared with aqueous dyed polyester.

2.7.3. X-ray diffraction (XRD) analysis

XRD (LabX XRD-6100 SHIMADZU, Japan) analysis of undyed, aqueous dyed and GES dyed polyester fabric was performed on Shimadzu 6100 instrument which is equipped with Cu K_{α} radiation. Scanning range of 2θ was kept between $10\text{--}35^{\circ}$, with a step size of 0.02° and $2^{\circ}/\text{min}$ scanning speed of detector.

3. Results and discussion

3.1. FTIR analysis of GES

The chemical interaction between choline chloride, urea and glycerin was characterized by FTIR analysis as shown in Fig. 1. Table 1 represents their respective functional groups and their observed bands. Due to the bending of N-H to the carbonyl group, amide group show two bands in the range of $1510\text{--}1700\text{ cm}^{-1}$. A strong absorbance band was observed at 1616 cm^{-1} indicating carbonyl group whereas 1616 cm^{-1} and 1664 cm^{-1} absorbance bands were attributed to the amide group. Sharp bands of aliphatic chain like $-\text{CH}_2$ and $-\text{CH}_3$ of glycerine were observed at 1041 cm^{-1} and 1446 cm^{-1} . A small absorbance band was observed at 3184 cm^{-1} which represents its interaction with carbonyl group resulting in symmetric N-H stretching. Absorbance band of 3330 cm^{-1} was observed

which indicates O-H stretching of hydroxyl group. It can be confirmed that all the parental functional groups of choline chloride, urea and glycerin are present in GES (Abbott et al., 2003; Ashworth et al., 2016; Mulia et al., 2015; Shamsuri and Abdullah, 2011). From FTIR spectrum of GES, hydrogen bonding was observed between choline chloride and hydrogen bond donor compounds (Shenai, 1997).

3.2. Optimization of dyeing of polyester using GES as a medium

The optimization of dyeing parameters of polyester dyeing with GES as a medium of dyeing was performed by keeping liquor to goods ratio 20:1 and compared with conventional aqueous dyed polyester for achieving better fastness properties.

3.2.1. Effect of pH on dyeing of polyester using GES as a medium

The colour strength of dyed polyester in terms of K/S was measured for dyeings carried out at pH ranging from 1 to 9 and is shown in Fig. 2. It was observed that as pH of dyeing solution increases the colour strength of dyed polyester fabric decreases. The higher colour strength was observed at pH 1, 3 and 7 but generally polyester dyeing is carried out in acidic pH. Due to higher strength loss in lower acidic medium subsequent dyeing was performed at pH 3. From this study, it is concluded that pH 3

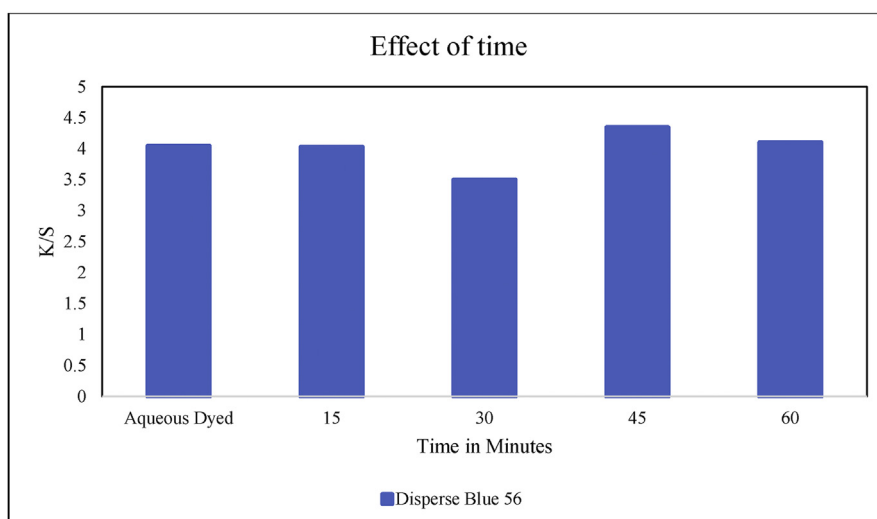


Fig. 4. Effect of variation of dyeing time intervals on colour strength of GES dyed polyester compared with aqueous dyed polyester.

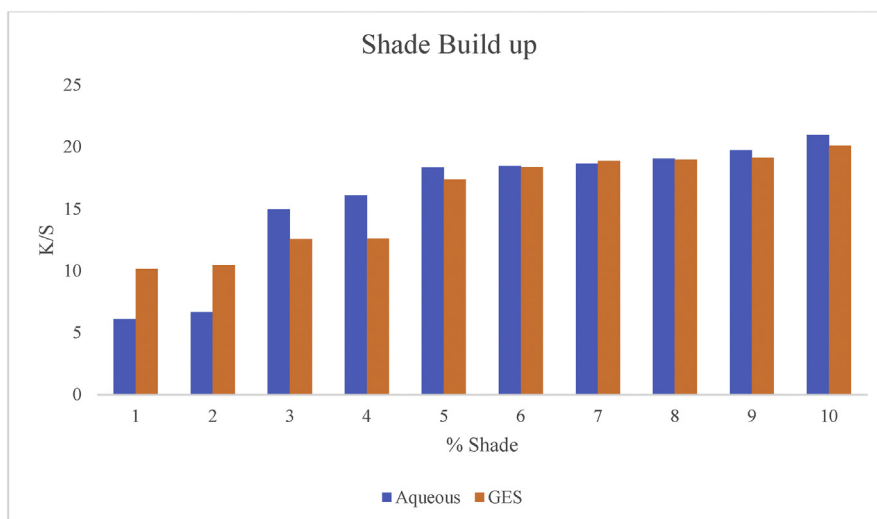


Fig. 5. Effect of shade build up on colour strength of GES dyed polyester compared with aqueous dyed polyester.

Table 2

1 % Aqueous and GES dyed polyester fabric with optimized recipe.

Aqueous dyeing	GES dyeing
% Shade: 1 %	% Shade: 1 %
Leveling Agent: 3%	Leveling Agent: 3%
Dispersing Agent: 2%	Dispersing Agent: NIL
Acetic Acid: 20%	Acetic Acid: 20%
liquor to goods ratio: 20:1	liquor to goods ratio: 20:1
Time: 45 min	Time: 45 min
Temp.: 130 °C	Temp.: 130 °C
pH: 4-5	pH: 3

Table 3

Colour co-ordinates of aqueous and GES dyed polyester fabrics.

Parameters	Fabric	
1 % Shade	Aqueous	GES
K/S	6.6791	10.4583
% Strength	100	156.57
L*	28.853	29.108
a*	1.513	-0.072
b*	-33.774	-32.252
C*	33.808	32.252
H*	272.6	269.836

is optimum for dyeing of polyester using GES as a medium.

3.2.2. Effect of temperature on dyeing of polyester using GES as a medium

The effect of variation of temperature on colour strength of GES dyed polyester compared with conventional aqueous dyeing is shown in Fig. 3. From Fig. 3, it can be observed that as temperature of dye bath increases the colour strength of dyed polyester fabric also increases up to

Table 4

Sublimation fastness rating of aqueous dyed and GES dyed polyester fabrics.

	150 °C			180 °C			210 °C		
	P	Q	R	P	Q	R	P	Q	R
Aqueous	4-5	4-5	4-5	4	4-5	4-5	3	4	3-4
GES	4-5	4-5	4-5	4	4-5	4-5	3-4	4	4

(P and Q denotes staining on polyester and cotton respectively whereas R denotes change in colour).

equilibrium after which it decreases with increase in dyeing temperature. This variation may be ascribed to the shift of equilibrium of dye from fabric to dye bath (Kale et al., 2015; Ramezanzadeh et al., 2015; Tayade and Adivarekar, 2013). Thus, dyeing temperature of 130 °C was optimized for dyeing of polyester using GES as a solvent as there was no significant difference in colour strengths at 130 °C and 140 °C respectively.

3.2.3. Effect of time on dyeing of polyester using GES as a medium

Fig. 4 shows colour strength of GES dyed polyester for different dyeing time intervals varying from 15 to 60 min and then compared with conventional dyed polyester. Dyeings were performed at 130 °C for different time intervals in acidic pH 3. Similar trend was observed as in case of effect of temperature. As dyeing time increases colour strength also increases till dyeing equilibrium is achieved. Further colour strength decreases with increase in time of dyeing (Shenai, 1997; Tayade and Adivarekar, 2013). After 15 min and 45 min of dyeing, more or less similar colour strength was observed. Maximum colour strength and even dyeing was observed after 45 min of dyeing. So, further study was carried out at optimized pH and temperature for 45 min.

3.2.4. Dyeing of polyester with optimum dyeing condition at varying shade %

To understand the buildup of shade, dyeing in aqueous and GES media was carried out on polyester fabric with different levels of shade % considering 1, 2, 3, 4, 5, 6, 7, 8, 9, 10% respectively as illustrated in Fig. 5. It illustrates that 1 % and 2 % shades of GES dyed polyester shows better colour strength than that of aqueous dyed polyester. Further increase in % shade (up to 5 %), the colour strength of aqueous dyed polyester shows higher dye uptake than GES dyed polyester. Such dyeing behavior may be due to the saturation of dye which is up to the 5 % shade in both aqueous and GES medium. After 5 % shade, both aqueous and GES dyed polyester shows comparable colour strength. From shade build up study, it is observed that as concentration of dye in dye bath increases colour strength of dyed polyester also increases until maximum dye uptake is achieved.

3.2.5. Comparison between aqueous and GES dyeing with optimized recipe and their colour coordinate values in terms of L*, a*, b*

Table 2 represents the optimized recipe of GES dyeing and comparison of GES dyed fabric with aqueous dyed polyester fabric.

Table 3 shows that the values of % strength, L*, a* and b* values of 1 % aqueous and GES dyed polyester fabric. Higher colour strength and L* value was observed in the GES dyed polyester indicating higher dye uptake as well as darker in shade than that of aqueous dyed polyester. a*

Table 5

Wash and light fastness rating of aqueous and GES dyed polyester fabrics.

	Wash Fastness			Light fastness
	A	B	C	C
Aqueous	4-5	4-5	4-5	7
GES	4-5	4-5	4-5	7

Table 6

Tensile strength of aqueous and GES dyed polyester fabrics.

	Tensile Strength (Kgf)		Elongation (%)	
	Warp	Weft	Warp	Weft
Undyed	26.08	25.17	56.55	57.05
Aqueous	24.50	23.06	51.9	54.47
GES	23.92	22.87	51.55	54.03

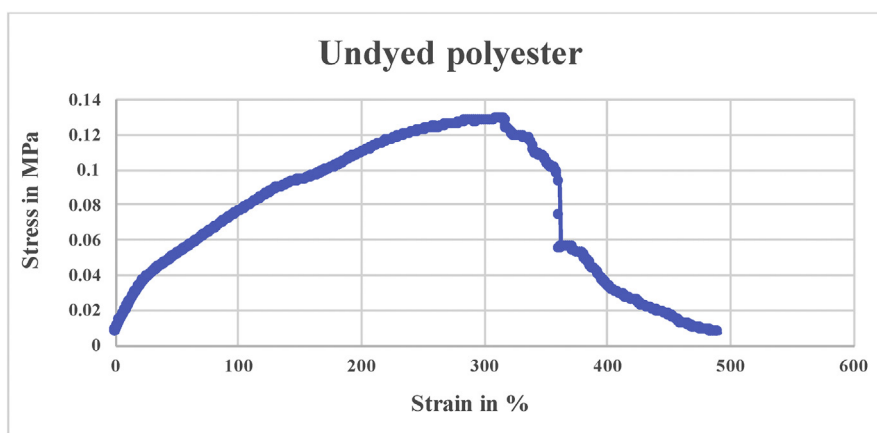
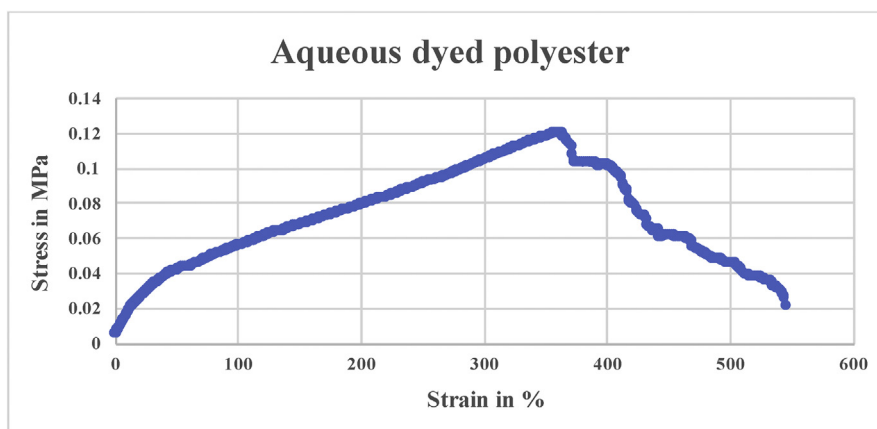
fabric. At 210 °C, GES dyed polyester showed better rating than that of aqueous dyed polyester. More staining was observed on adjacent polyester and cotton whereas slightly colour change was observed on GES dyed polyester.

Table 5 represents the rating of wash and light fastness of aqueous and GES dyed polyester. No major change was observed on washing as well as light fastness of aqueous and GES dyed polyester fabric. Both aqueous as well as GES dyed polyester showed almost similar and very good results.

3.4. Mechanical and physical properties of polyester

3.4.1. Tensile strength

Measurement of tensile strength was performed on undyed, aqueous dyed and GES dyed polyester fabric and represented in Table 6. From Table 6, it was observed that the tensile strength of undyed polyester

**Fig. 6.** Stress-strain curve of undyed polyester fabric.**Fig. 7.** Stress-strain curve of aqueous dyed polyester fabric.

and b* values of GES dyed polyester showed more greener and less bluer tone respectively.

3.3. Colour fastness properties of dyed polyester

Table 4 represents the sublimation fastness rating of polyester dyed fabrics at 150 °C, 180 °C, 210 °C and found to be good to very good for both aqueous as well as GES dyeing. At 150 °C and 180 °C, it has been observed that aqueous dyed polyester shows similar results as compared to GES dyed polyester. Some staining was observed on adjacent polyester

fabric showed higher strength as compared to aqueous and GES dyed polyester. Aqueous and GES dyed polyester fabrics showed almost similar tensile strength but lesser strength loss than undyed polyester fabric. Similar trend was observed in both warp and weft direction. To study mechanical properties of undyed, aqueous dyed and GES dyed polyester fabric stress-strain curve was analyzed which is shown in Figs. 6, 7, and 8 respectively. Ultimate tensile strength of undyed, aqueous dyed and GES dyed polyester fabrics are 0.129 MPa, 0.120 MPa and 0.128 MPa respectively (Jirawattanasomkul et al., 2019). The modulus of elasticity or young's modulus of undyed, aqueous dyed and GES dyed polyester

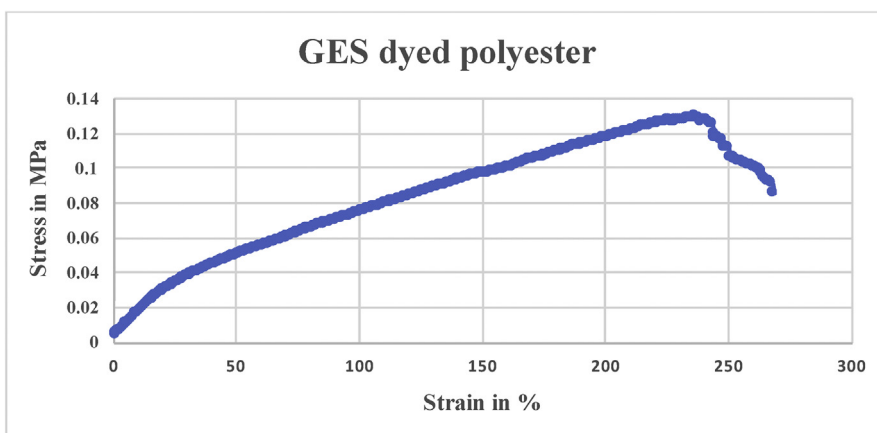


Fig. 8. Stress-strain curve of GES dyed polyester fabric.

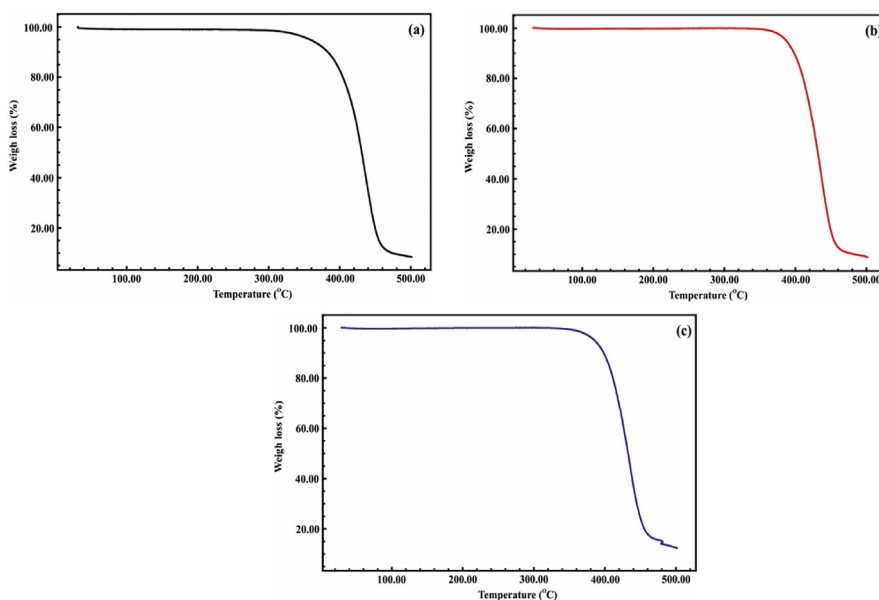


Fig. 9. TGA of undyed polyester (b) TGA of aqueous dyed polyester (c) TGA of GES dyed polyester.

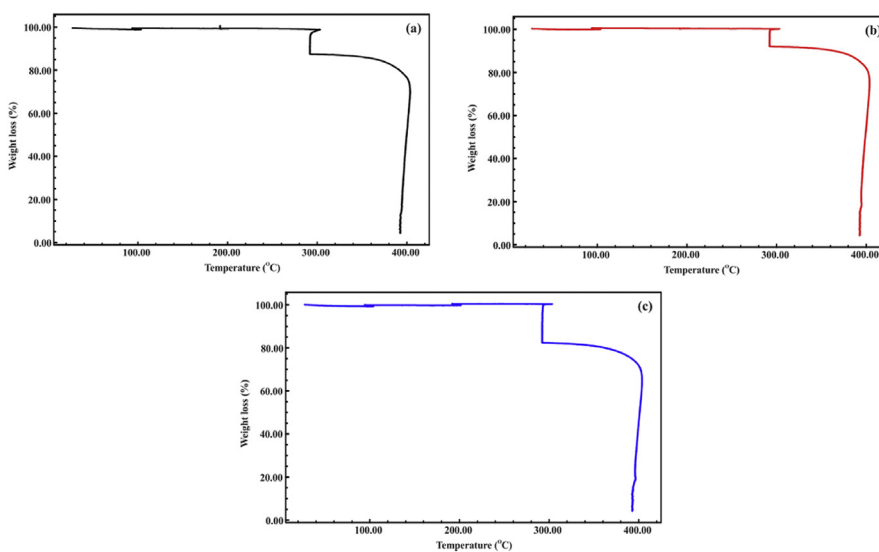


Fig. 10. Static TGA of undyed polyester (b) Static TGA of aqueous dyed polyester (c) Static TGA of GES dyed polyester.

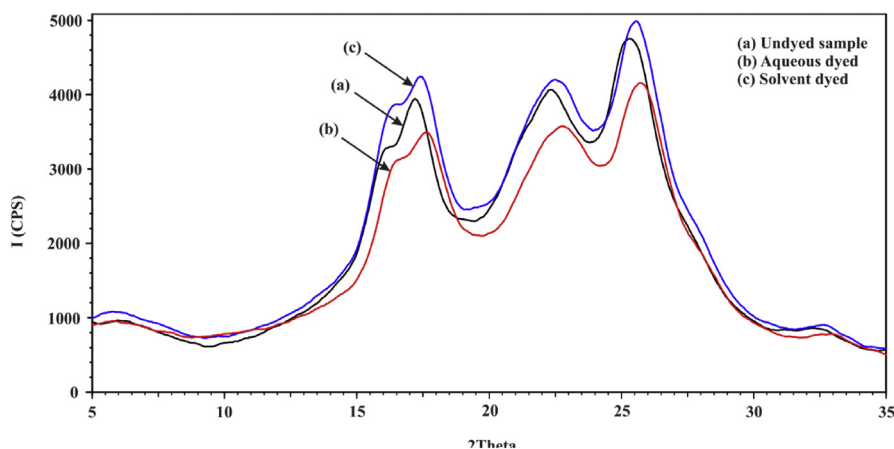


Fig. 11. X-ray diffractograms undyed, aqueous dyed and GES dyed polyester fabrics.

fabric were calculated using 10 different observations and their calculated mean modulus of elasticity or young's modulus are 0.00055 MPa, 0.00031 MPa and 0.00070 MPa respectively. From this it can be concluded that GES dyed fabric is slightly stiffer than control polyester fabric. Overall negligible tensile strength loss was observed in aqueous dyed and GES dyed polyester fabric.

3.4.2. Thermogravimetric analysis

Fig. 9 illustrates the comparison of thermal properties between undyed, aqueous and GES dyed polyester fabric. It has been observed that thermal stability of undyed polyester is lower than aqueous and GES dyed polyester. Decomposition of undyed polyester started at 380 °C whereas decomposition of aqueous dyed and GES dyed polyester started at 400 °C. After 450 °C, 90.98 %, 91.07 % and 87.59 % weight loss was observed for undyed, aqueous and GES dyed polyester respectively. Therefore, such results indicate that GES dyed polyester is thermally more stable than undyed and aqueous dyed polyester. To check long term thermal stability of undyed, aqueous dyed and GES dyed polyester, static TGA analysis was carried out at 100 °C, 200 °C, 300 °C and 400 °C for 2 hours which is represented in Fig. 10. It has been observed that no significant thermal degradation of undyed, aqueous and GES dyed polyester was observed below 300 °C whereas 11.56 %, 7.87 % and 17.63 % weight loss of undyed, aqueous and GES dyed polyester was observed while keeping polyester fabric at 300 °C for 2 hours. This phenomenon might be attributed due to degradation of ester linkages of polyester. Thermal degradation of undyed, aqueous dyed and GES dyed polyester starts after 350–360 °C (Sreenivasan et al., 2015; Yong et al., 2015). Significant weight loss was observed while polyester fabric kept at 400 °C for 2 hours. The measured weight loss between 300 to 400 °C of undyed, aqueous dyed and GES dyed polyester fabrics were 22.13 %, 18.05 % and 28.48 % respectively. Around 96 % of weight loss was observed while keeping undyed, aqueous dyed and GES dyed polyester fabrics at 400 °C for 2 hours. From both TGA analysis it was clearly seen that if polyester fabric is exposed at higher temperature for longer duration then its decomposition will be more.

3.4.3. X-ray diffraction

The effect of solvent on physical structure of polyester fabric was analyzed by X-ray diffraction analysis as shown in Fig. 11. X-ray diffraction curve of aqueous dyed and GES dyed polyester fabrics indicates no major change in crystallinity of polyester fabric. Slight shift in peaks of GES dyed and aqueous dyed polyester was observed and compared with undyed polyester. It represents molecules of dye entrapped physically in polyester fibres (Dumbleton and Bowles, 1966; Hsieh and Mo, 1987; Ochowicz and Jeziorny, 1972). Crystallinity % was evaluated by estimating area of sharp and broad peaks and calculated by using following formula (Kale et al., 2015).

$$\text{Crystallinity \%} = \frac{\text{Intensity of crystalline region}}{\text{Intensity of crystalline region} + \text{Intensity of amorphous region}} \times 100$$

Undyed polyester fabric shows better crystallinity than aqueous and GES dyed polyester fabrics. Evaluated crystallinity of undyed, aqueous and GES dyed polyester fabrics are 28.02 %, 23.56 % and 24.73 % respectively. Due to dye-fibre interaction crystallinity of dyed fabric decreases as compared with undyed polyester fabric (Opwis et al., 2013). No major crystallinity difference was observed between aqueous and GES dyed polyester fabrics. This it can be concluded that use of GES as a dyeing medium has no effect on the physical structure of polyester fabric.

4. Conclusion

In the present research work, an eco-friendly glycerine based eutectic solvent (GES) was successfully used as a dyeing medium for polyester using Disperse Blue 56. The GES was prepared using glycerine, urea and choline chloride; confirmed by FTIR spectroscopy. The application of GES as a dyeing medium in polyester dyeing shows better results as compared to conventional aqueous dyeing. Wash and light fastnesses of aqueous and GES dyed polyester are almost similar whereas sublimation fastness of GES dyed polyester shows better results than that of aqueous dyed polyester. Modulus of rigidity of polyester fabric shows that GES dyed polyester is slightly stiffer than that of conventional aqueous dyed as well as undyed polyester fabric. From the XRD and tensile measurements, it is observed that the physical structure of polyester does not get affected after using GES as a dyeing medium. Static TGA analysis shows that the thermal degradation of undyed, aqueous dyed and GES dyed polyester starts above 360 °C. Similarly, there happens to be no such deterioration in the thermal stability of GES dyed polyester. Such novel use of GES as a medium for solvent dyeing of polyester can be a sustainable approach in textile industries.

Declarations

Author contribution statement

Sushant S Pawar: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Saptarshi Maiti, Santosh Biranje: Analyzed and interpreted the data. Kedar Kulkarni: Contributed reagents, materials, analysis tools or data.

Ravindra V. Adivarekar: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Funding statement

S. Pawar, S. Maiti and S. Biranje were supported by a scholarship from University Grants Commission-Basic Scientific Research (UGC-BSR) (award letter number F.25-1/2014-15 (BSR)/No. F.5-65/2007 (BSR)).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

- Abbott, A.P., Bell, T.J., Handa, S., Stoddart, B., 2006. Cationic functionalisation of cellulose using a choline based ionic liquid analogue. *Green Chem.* 8, 784.
- Abbott, A.P., Capper, G., Davies, D.L., Rasheed, R.K., Tambyrajah, V., 2003. Novel solvent properties of choline chloride/urea mixtures. *Chem. Commun.* 1, 70–71.
- Andrade, R., Torres, D., Ribeiro, F.R., Chiari-Andréo, B.G., Oshiro Junior, J.A., Iglesias, M., 2017. Sustainable cotton dyeing in nonaqueous medium applying protic ionic liquids. *ACS Sustain. Chem. Eng.* 5, 8756–8765.
- Ashworth, C.R., Matthews, R.P., Welton, T., Hunt, P.A., 2016. Doubly ionic hydrogen bond interactions within the choline chloride-urea deep eutectic solvent. *Phys. Chem. Chem. Phys.* 18, 18145–18160.
- Bianchini, R., Cevasco, G., Chiappe, C., Pomelli, C.S., Rodríguez Douton, M.J., 2015. Ionic liquids can significantly improve textile dyeing: an innovative application assuring economic and environmental benefits. *ACS Sustain. Chem. Eng.* 3, 2303–2308.
- Blackburn, R., 2015. Sustainability Challenges of the Textiles, Dyeing and Finishing Industries: Opportunities for Innovation. ACS Webinar.
- Chavan, R.B., Subramanian, A., 1982. Dyeing of Cellulosic Fibres with a Reactive Dye from Acetone-Water Mixture, vol. 7, pp. 101–106.
- Chen, L., Wang, L., Wu, X., Ding, X., 2017. A process-level water conservation and pollution control performance evaluation tool of cleaner production technology in textile industry. *J. Clean. Prod.* 143, 1137–1143.
- Dadrasnia, A., Ismail, S., 2015. Biosurfactant production by *Bacillus salmalaya* for lubricating oil solubilization and biodegradation. *Int. J. Environ. Res. Public Health* 12, 9848–9863.
- Delgado-mellado, N., Larriba, M., Navarro, P., Rigual, V., Ayuso, M., García, J., Rodríguez, F., 2018. Thermal stability of choline chloride deep eutectic solvents by TGA/FTIR-ATR analysis. *J. Mol. Liq.* 260, 37–43.
- Dumbleton, J.H., Bowles, B.B., 1966. X-ray determination of crystallinity and orientation in poly(ethylene terephthalate). *J. Polym. Sci. A-2 Polym. Phys.* 4, 951–958.
- Ferrero, F., Periolatto, M., 2012. Glycerol in comparison with ethanol in alcohol-assisted dyeing. *J. Clean. Prod.* 33, 127–131.
- Ferrero, F., Periolatto, M., Rovero, G., Gianetti, M., 2011. Alcohol-assisted dyeing processes: a chemical substitution study. *J. Clean. Prod.* 19, 1377–1384.
- Gebert, K., 1971. The Dyeing of Polyester Textile Fabric in Perchloroethylene the Exhaust Process. *Exhaust Dye. Polyest. Perchloroethylene*, pp. 509–513.
- Glynis, S., 2015. Fast Fashion Is the Second Dirtiest Industry in the World, Next to Big Oil [WWW Document].
- Hsieh, Y., Mo, Z., 1987. Crystalline structures of poly (ethylene terephthalate) fibers. *J. Appl. Polym. Sci.* 33, 1479–1485.
- Jirawattanasomkul, T., Kongwang, N., Jongvivatsakul, P., Likitlersuang, S., 2019. Finite element modelling of flexural behaviour of geosynthetic cementitious composite mat (GCCM). *Compos. B Eng.* 165, 702–711.
- Kale, R.D., Banerjee, A., Katre, G., 2015. Dyeing of polyester and polyamide at low temperature using solvent crazing technique. *Fibers Polym.* 16, 54–61.
- Kant, R., 2012. Textile dyeing industry an environmental hazard. *Nat. Sci.* 4, 22–26.
- Kaur, P., Rajani, N., Kumawat, P., Singh, N., Kushwaha, J.P., 2018. Performance and mechanism of dye extraction from aqueous solution using synthesized deep eutectic solvents graphical abstract. *Colloids Surf., A* 539, 85–91.
- Milicevic, B., 1967. The use of non-aqueous solvents in coloration and textile processing I-literature. *Survey. Rev. Prog. Color. Relat. Top.* 2, 49–52.
- Morita, Z., Kobayashi, R., Motomura, H., 1975. Fundamental studies on solvent dyeing with tetrachloroethylene. I. Diffusion of disperse dyes in poly(ethylene terephthalate). *J. Appl. Polym. Sci.* 19, 1095–1102.
- Mulia, K., Krisanti, E., Terahadi, F., Putri, S., 2015. Selected natural deep eutectic solvents for the extraction of ??-Mangostin from mangosteen (*Garcinia mangostana* L.) pericarp. *Int. J. Technol.* 6, 1211–1220.
- Ochowicz, A.W., Jeziorny, A., 1972. Determination of crystallinity in polyester fibers by X-ray methods. *J. Polym. Sci. Part A 2* 10, 1407–1414.
- Opwis, K., Gutmann, J.S., Knittel, D., 2013. Dyeing of Textile Materials in Ionic Liquids.
- Peng, X., Lou, K., Zhang, Y., Li, M., Wen, S., Cai, Y., 2017. Ammonified modification and dyeing of ramie fabric in liquid ammonia. *Dyes Pigments* 138, 154–161.
- Radei, S., Carrión-Fité, F.J., Ardanuy, M., Canal, J.M., 2018. Kinetics of low temperature polyester dyeing with high molecular weight disperse dyes by solvent microemulsion and agrosourced auxiliaries. *Polymers (Basel)* 10.
- Ramezanzadeh, B., Ghasemi, E., Mahdavian, M., Changizi, E., Mohamadzadeh Moghadam, M.H., 2015. Covalently-grafted graphene oxide nanosheets to improve barrier and corrosion protection properties of polyurethane coatings. *Carbon N. Y.* 93, 555–573.
- Shamsuri, A., Abdullah, D., 2011. Complexation reaction using ammonium based chloride compounds for preparation of eutectic mixtures. *Int. J. Chem.* 3, 161–165.
- Shenai, V.A., 1997. *Technology of Textile Processing*, second ed.
- Sreenivasan, V.S., Rajini, N., Alavudeen, A., Arumugaprabu, V., 2015. Dynamic mechanical and thermo-gravimetric analysis of *Sansevieria cylindrica*/polyester composite: effect of fiber length, fiber loading and chemical treatment. *Compos. B Eng.* 69, 76–86.
- Tayade, P.B., Adivarekar, R.V., 2013. Dyeing of cotton fabric with cuminum cyminum L. as a natural dye and its comparison with synthetic dye. *J. Text. Inst.* 104, 1080–1088.
- Wang, Y., Lee, C. hao, Tang, Y. lun, Kan, C. wai, 2016. Dyeing cotton in alkane solvent using polyethylene glycol-based reverse micelle as reactive dye carrier. *Cellulose* 23, 965–980.
- Xu, S., Chen, J., Wang, B., Yang, Y., 2015. An environmentally responsible polyester dyeing technology using liquid paraffin. *J. Clean. Prod.* 112, 987–994.
- Yong, C.K., Ching, Y.C., Chuah, C.H., Liou, N.S., 2015. Effect of fiber orientation on mechanical properties of kenaf-reinforced polymer composite. *BioResources* 10, 2597–2608.
- Yuan, J., Wang, Q., Fan, X., 2010. Dyeing behaviors of ionic liquid treated wool. *J. Appl. Polym. Sci.*