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Enhancement of dyeing Technology of Polyester fabric with disperse red 167 using ZnO Nano Powder

ELsisi A. A , Emam A. A. , Gomaa S.H , Ahmed H.M

Department of Chemistry, Faculty of Science, Al-Azhar University (Girls), Nasr City, Cairo, Egypt

Abstract: *The aim of the research was to investigate nano technique of polyester disperse dyeing without the presence of acid auxiliary agent which causes fabric damage. Dyeing of untreated and pre-treated polyester fabrics were carried out in the temperature range between 75 and 105°C using Disperse Red 167 to compare the results. For each dyeing temperature, the exhaustion curves of the dye bath were determined and the better results of dyeing kinetics were obtained in case of pre-treated fabric. The corresponding dye adsorption rate constants according to, pseudo-second order, and intra-particle diffusion kinetic models were examined and calculated. Moreover, the diffusion coefficients and activation energies were also evaluated. The partition coefficient and standard affinity at various temperatures were determined for the Disperse Red 167 onto polyester fabric. The corresponding thermodynamic parameters, enthalpy and entropy changes, of conventional dyeing using untreated polyester and novel dyeing using pre-treated polyester-fabrics were also compared. The obtained results confirm the possibility of reducing temperature, using less dyestuff, and saving energy of conventional dyeing of polyester -fabrics with a disperse dye via fabric pre- treatment.*

Key words: *Polyester fabrics, Disperse dye, ZnO nano powder, Kinetic and thermodynamic parameters*

INTRODUCTION

Polyester fiber has a highly compact and crystalline structure, and is markedly hydrophobic. For this reason, its aqueous dyeing is carried out at high temperature and high pressure using disperse dyes. Solvent-assisted and carrier dyeing has been widely studied as a mean of accelerating the dyeing rate, improving dye uptake and lowering dyeing temperature (GAMAL et al., 2010). However, both solvents and carriers have serious problems, namely toxicity and unpleasant odor, poor light fastness, an adverse effect on the physical and chemical properties of the fiber, high costs of waste water treatment and environmental contamination and destruction. Clearly, it seems sensible that efforts should be devoted toward the development of a new dyeing technique to accelerate dyeing rate, improve dye uptake and lower dyeing temperature. Nanotechnology can be applied to many areas in textiles. Comprehensive research efforts have been made in the area of disperse dyes that have been used for the dyeing of hydrophobic fabrics [2-5]. Consequently, in the last two decades, the research trends focused their efforts on the application of new technologies (El-Shafei et al., 2011) such as nano technology, to modify and develop the dye ability of polyester fabric.

ZnO nanoparticles have well-organized large surface area, high catalytic (Wang, 2004; Chen & Tang, 2007), optical, and photo catalytic activities (Suchea et al., 2006; Ashour et al.,2006), hence, they were extensively used to produce ultraviolet-protective, and self-cleaning materials (Alya et al.,2016).

In the present research, synthesized Zinc oxide (ZnO) nano powder was chosen for pre- treatment of polyester fabric. The dyeing behavior at various temperatures was compared with a traditional dyeing without using chemical auxiliaries. Studying the kinetic and thermodynamic adsorption parameters in addition to diffusion properties are of great concern for enhancing, the dyeing ability of Polyester fabric with disperses red 167 using ZnO Nano Powder.

2. Experimental

2.1. Dye and Fabric

Disperse red167 (DR167) was kindly supplied by DyStar. The structure is represented in Figure1. Scoured and bleached 100%polyester (0.22 dtex) fabric was supplied by El-Mahalla El-Kobra Company. The fabrics were further scoured in aqueous solution with a liquor ratio 1:50containing 2 g/l nonionic detergent solution (Hostapal, Clariant) and 2 g/l Na_2CO_3 at 50°C for 30 min to remove waxes and impurities, then rinsed thoroughly in cold tap water, and dried at room temperature. All other chemicals were purchased with high purity from Merck (Darmstadt, Germany)

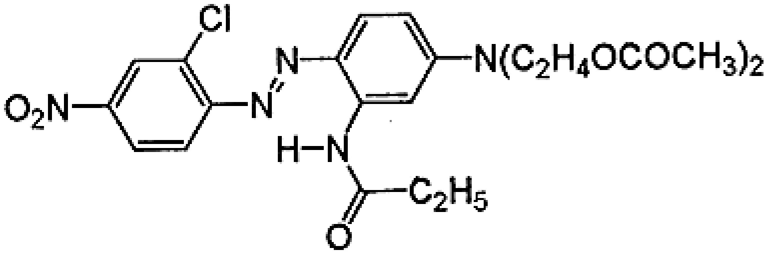

Figure 1. Chemical structure of Disperse red167

2.2. Preparation of ZnO NPs

ZnO NPs were prepared using a novel precipitation method.0.01 M Zinc acetate (2.19 g) was dissolved in 50 mL of distilled water. 0.01 M of solid ammonium oxalate (1.42 g) powder was accurately weighed and added to the zinc acetate solution. The suspension was stirred till the dissolution of ammonium oxalate took place. Ammonia solution was added drop wise to raise the pH of the solution to 10. Slowly a white precipitate of zinc oxalate was formed. The obtained precipitate was separated by filtration and washed repeatedly with distilled water. The wet zinc oxalate particles obtained was dried in air for 24 h, and then dried in hot air oven at 110◦C for 90 min. The dry powder obtained was care-fully collected in silica crucible and heated in a muffle furnace at700◦C for about 3 h. During calcination, zinc oxalate had under-gone decomposition as per the following equation and leads to the formation of ZnO NPs. (Jeyasubramaniana et al., 2015).

$$Zn(CH_3COO)_2+(COONH_4)_2 \quad \frac{\mathrm{NH4OH}}{\mathrm{(pH10)}} \quad ZnC_2O_2+CH_3COOH+H_2O+N_2 \qquad \uparrow$$

$$\text{Zinc acetate} \quad \frac{ammonium}{oxalate} \quad \text{Zinc Oxalate}$$

$$2ZnC_2O_4 + O_2 \xrightarrow{\Delta 7000_C} 2ZnO + 4CO_2 \quad \uparrow$$

2.3 Fabric pre- treatment with zinc oxide nano powder

The fabric samples were soaked for 20 min. in 2-propanol (98%) dispersion of ZnO nano powder (5% w/w) under gentle magnetic stirring. The fabrics were squeezed to remove the excess dispersion and dried in an oven at70 ^{0} C for 15 min. under atmospheric pressure [11-13]. The fabrics were querying at 140 °C for 3 min., then were washed in aqueous solution with a liquor ratio1:50 containing 3 g/l nonionic detergent solution (Hostapal, Clariant) at 60 °C for 15min.

2.4. Dyeing Process

To determine the dyeing process behavior of polyester fabric with DR167 at different temperatures, the dye solution was prepared by dissolving it (1.0 g of dye) in 5 ml of DMF in presence of dispersing agent then Pre-treated or untreated fabric samples (1g) were introduced in a flask containing the dye bath of 2 %

of dye over time intervals of 120 min at, 75, 85, 95, and 105°C with 1:50 liquor ratio at pH adjusted to 4.2 using acetic acid At the end of dyeing, the residual dye bath concentrations were measured with an UV-vis spectrophotometer (Perkin Elmer Lambda 35, USA) at λ_{max}.

2.5. Exhaustion %

The following equation was used to determine Exhaustion %

$$Exhaustion\ \% = \frac{C_o - C_e}{C_o} \text{ x } 100 \qquad (1)$$

Where C_0 and C_e are the concentrations of dye originally present in the dye bath and that of the residual dye in the dye bath at specific time respectively.

2.6. Adsorption Kinetic Modeling

To evaluate the adsorption kinetics of DR167 onto polyester fabric, pseudo-first order (Errais et al., 2016) pseudo-second order (Alver & Metin, 2012) and intra-particle diffusion (Elsherbiny et al.,2012) kinetic models were investigated to fit the experimental data obtained at different temperatures.

1st order kinetic model

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \qquad (2)$$

2nd order kinetic model

$$\frac{t}{q_t} = \frac{1}{k_2 {q_e}^2} + \frac{t}{q_e} \qquad (3)$$

Intra-particle diffusion model

$$q_t = k_p t^{1/2} + C \qquad (4)$$

Where q_e and q_t are the dye adsorbed per unit weight of fabric (mg g^{-1}) at equilibrium and at any time t, respectively; k_1 is the rate constant for 1st order reaction (min^{-1}), k_2 is the rate constant for 2nd order reactions (mg g^{-1} min^{-1}) , k_p is rate constant for intra-particle diffusion (mg g^{-1} min^{-1}) C is the intercept of intra-particle diffusion equation (mg g^{-1}).

Different methodologies were suggested to calculate the diffusion coefficient, D (cm^2 sec^{-1}), of dye into fabric in dying process. Hill's equation, Eq.5. (Shoar et al., 2009) was employed to determine the diffusion coefficient of dye into the fabric. The activation energy of the diffusion was calculated according to Arrhenius's equation, Eq.6. (Rabiei et al., 2012)

$$D = \frac{\pi r^2}{16t}\left(\frac{C_t}{C_e}\right)^2 \qquad (5)$$

$$\ln D = \ln D_o - \frac{E}{RT} \qquad (6)$$

Where C_t and C_e represent the dye concentrations in solution at time t and at equilibrium (mg L^{-1}); r is a radius of the cylindrical fiber (cm); E is the activation energy (kJ mol^{-1}); D_0 is a constant; R is a gas constant (8.314 J mol^{-1} K^{-1}) and T is the absolute temperature (K).

2.7. Thermodynamic Parameters

The partition coefficient, of the dye concentration between the fiber and the dyeing solution was obtained from the adsorption isotherm. The standard affinity of the dye was calculated using the following equation (7):

$$-\Delta\mu^o = RTln\frac{[D]_f}{[D]_s} = RTlnK \qquad (7)$$

Where $-\Delta\mu^0$ is a standard affinity (kJ mol^{-1}), and $[D]_f$ and $[D]_s$ are dye concentrations in fiber (mg g^{-1}) and in solution (mg ml^{-1}), respectively.

The dyeing enthalpy change was obtained from the empirical plot of the Clausius-Clapeyron equation (8), and the enthalpy change can be calculated from the slope of the straight line of Eq. (8). The dyeing entropy change was calculated from the experimental plot of the relation between $-\Delta\mu^{O}$ and T, Eq.(9).

$$\frac{\Delta H^{O}}{T} = \frac{\Delta\mu^{O}}{T} + Const. \qquad (8)$$

$$-\Delta\mu^{O} = T\Delta S^{O} - \Delta H^{O} \qquad (9)$$

Where ΔH^{0} is enthalpy change, heat of dyeing, (kJ mol^{-1}); $Const.$ is an integral constant; ΔS^{0} is the change in entropy (kJ mol^{-1} K^{-1}).

2.8. Characterization

The morphological studies of as obtained ZnO NPs were carried out using scanning electron microscopy (SEM), JEOL, JSM6390, Japan. The phase identification and crystal geometry of ZnO NPs were obtained using X-ray diffraction analysis (XRD) recorded by employing P analytical X'Pert Powder X'Celerator Diffractometer.

RESULTS AND DISCUSSION 3.

3.1. X-ray diffraction analysis

The XRD pattern recorded as obtained ZnO NPs with 2θ ranging from 10° to 60° is represented in Fig. 2. The diffracted peaks at 2θ = 31.8530, 34.5211, 36.3391, 47.6193 and 56.6715 were assigned to (1 0 0), (2 0 0), (1 0 1), (1 0 2), and (1 1 0) lattice planes respectively in accordance with JCPDS No. 89-1397. All these data reveal about the structure of ZnO NPs as hexagonal wurtzite structure. Mostly zinc oxide exhibit wurtzite hexagonal structure since it is a stable one where each Zn^{2+} is packed with four O^{2-} at the corners of a tetrahedron (Renganathan et al., 2011).

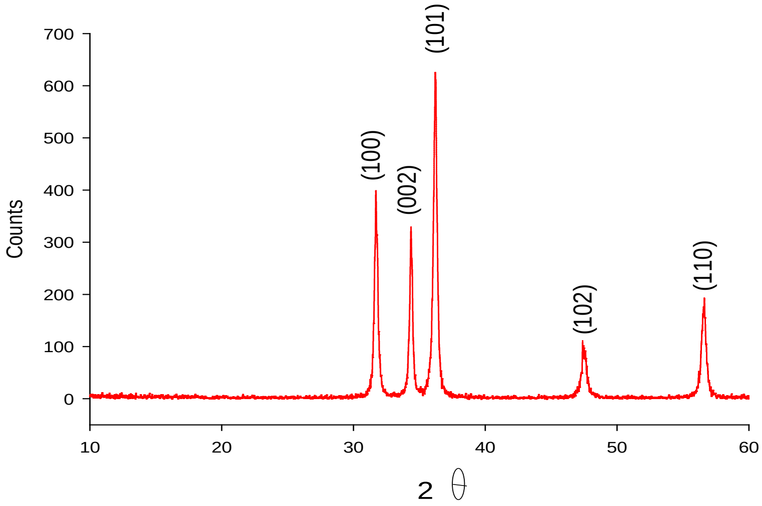

Figure 2. XRD spectrum of ZnO NPs.

The crystallite size of the as obtained ZnO NPs was evaluated using the Scherer's formula, which is given as,

$$D = \frac{K\lambda}{\beta \cos \theta} \qquad (10)$$

where k is the Scherer's constant and its value is taken as 0.9, λ is the wavelength of the XRD used which is 1.5406 Å, β is the full width at half maximum of the diffracted peak appeared at 2 θ. From the Scherer's formula, the average crystallite size was calculated as66 nm. From the data above, it is evident that, more the crystallite size more is the number of unit cells. Crystallite sizes with 82.98 nm possess a higher number of unit cells of 63, 14, 658.

3.2. EDX and Scanning electron microscopic analysis

Fig. 3a represents SEM image of the isolated ZnO NPs. It was recorded in the SE operation mode. It is clear from this figure that the morphology of the prepared ZnO NPs was spherical shaped with size ranges from 100 to 200 nm in diameter. The distribution of the particles present in the image was computed using Image J software and the obtained Histogram is shown as inset of Fig. 3a. From the inset, it is clear that the particles were poly dispersed with an average particle diameter of 175 nm. Fig. 3(b) shows the EDX spectrum of ZnO nanoparticles prepared by a novel precipitation method. The strong peaks observed in the spectrum related to Zinc and oxygen. The elemental constitution of ZnO nanoparticles with two major peaks was found to have weight percentage of 73.87 of Zinc and 26.13 of oxygen. The prepared ZnO nanoparticles have atomic percentage of 40.90 of Zinc and 59.10 of oxygen. This confirmed the formation of ZnO nanoparticles in all the three process.

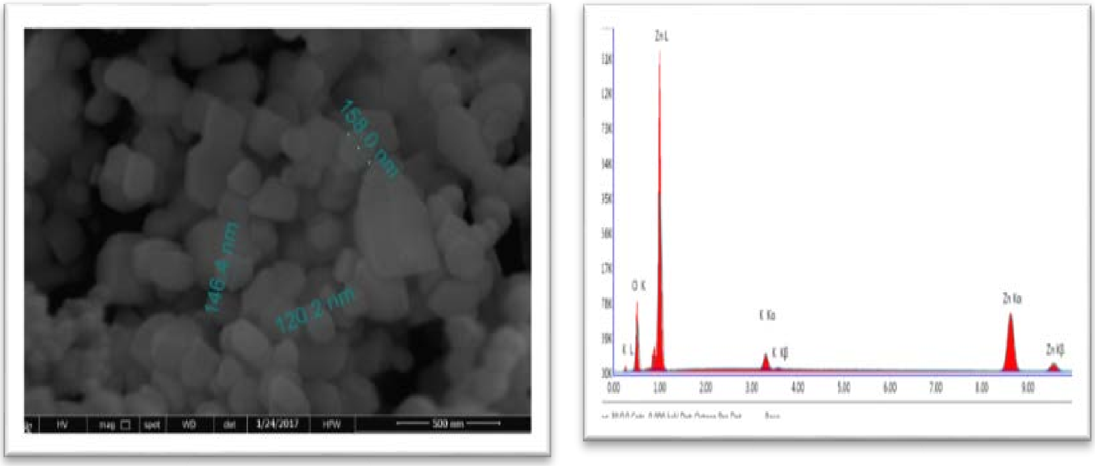

Figure 3. (a) EDS pattern of the ZnO nanoparticle. (b) SEM image of ZnO nanoparticles.

3.3. Dyeing kinetics

Time-exhaustion isotherms of untreated and pre-treated polyester fabrics using DR167 are shown in figure 4 (a, b). The figures show that the dye ability of DR167 onto pre-treated polyester fabric is generally better than that obtained by using untreated sample under the same conditions. Improvements observed in dyeing exhaustion% which reaches at 105C^0 to 98.55% for pre-treated sample compared with 72.20 % for untreated one are generally attributed to the ability of ZnO nano powder to form a thin layer onto polyester fabric during pre-treatment stage. This observation rises polyester hydrophobic properties and result in appearance of the micro- and nanoscopic architecture on the surface, which maximizes and accelerate the adhesion of the dye to the polyester fabric surface. The idea of producing hydrophobic surfaces was enlarged derived from Lotus effect (Alya et al., 2016; Al-Etaibi et al., 2016). Higher temperature resulted in an increase in dye exhaustion% onto fabrics; hence, the dye adsorption is an endothermic process (Taher et al., 2013).

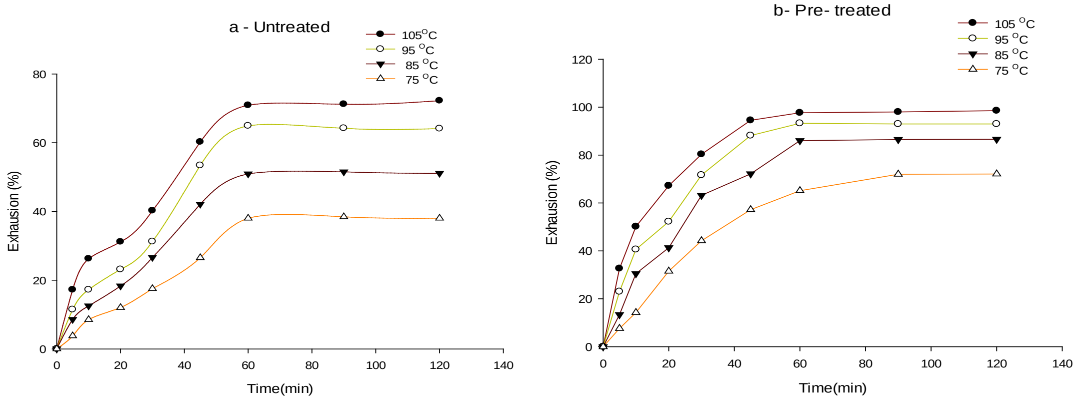

Figure 4. Time-Exhaustion isotherms of DR167 dye adsorption onto (a) untreated and (b) pre-treated polyester fabric at different temperatures

Adsorption kinetics are important from the point of view that it controls the efficiency of the process and the models correlate the adsorbate uptake rate with its bulk concentration. Therefore, the most practical parameters, i.e. dyeing rate constant, diffusion coefficient and activation energy of diffusion were determined for dyeing of both untreated and pre-treated fabrics. The experimental data shown in Figure 4(a, b) can be analyzed using three kinetic models that represented by Eq. 2,3 and 4 to determine the adsorption kinetics of DR167 onto polyester fabrics at temperature range 75-105ºC. The kinetic data of adsorption process towards temperature are given in Table 1 and it is observed that adsorption increases with the increase in temperature. This indicates that the endothermic nature of the process is attributable to the tendency of dye molecules to escape from the bulk phase to solid phase with an increase in temperature of the dyeing bath.

Table 1. Kinetic parameters of the dyeing process of DR167 onto untreated and pre-treated polyester fabrics at different temperatures

Applying, pseudo-first order kinetic model, Eq. 2, The parameters $k_1$and $q_e$could be calculated from the slope and the intercept of the plots of log $(q_e - q_t)$ versus t, and are found to be unbeseeming for the present system. This suggests that the adsorption of DR167 onto untreated and pre- treated polyester fabrics did not follow the pseudo-first order kinetic model.

Fabric	**T ⁰ C**	**Pseudo- second order**			**Intra-particle diffusion**		
		q_e **(mgg⁻¹)**	K_2**x104 (mg g-1 min⁻¹)**	**r²**	K_p **(mg g-1 min-1/2)**	C ***(mg g⁻¹)***	**r²**
Untreated	75	23.98	6.88	0.9343	2.53	-4.96	0.9942
	85	31.54	7.35	0.9533	3.07	-3.10	0.9980
	95	41.60	*10.72*	0.9285	3.92	-4.22	0.9965
	105	45.64	11.20	0.9362	3.98	-1.61	0.9952
Pre-treated	75	46.29	3.85	0.9046	4.16	-7.24	0.9911
	85	55.86	4.95	0.9103	4.36	-4.09	0.9980
	95	57.47	6.67	0.9550	4.48	1.40	0.9900
	105	59.52	14.06	0.9897	4.67	7.65	0.9985

For the pseudo-second order kinetic model, Eq. 3, the q_e and k_2 values can be obtained from the slopes and intercepts of plots of $\frac{t}{q_t}$ versus t which are illustrated in Figure 5 a,b. The correlation coefficients of linear plots at different temperatures are higher than 0.9, which suggest that pseudo-second order kinetic model is better in describing the adsorption kinetics of DR167onto untreated and pre- treated polyester fabrics. This explains that the adsorption depends on the a adsorbate as well as the adsorbent and involves chemisorption process in addition to physisorption (Xiong et al., 2010). The parameters are listed in Table 1.

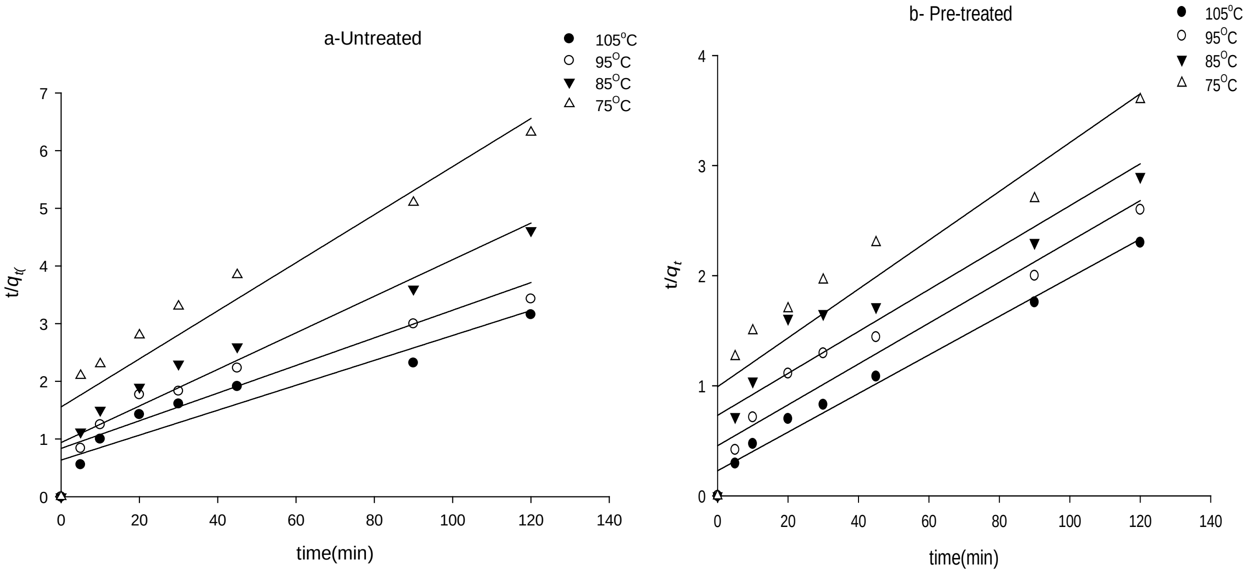

Figure. 5. Pseudo-second order adsorption kinetics of DR167 onto (a) untreated polyester. (b) pre –treated polyester fabrics at various temperatures. [Dyeing conditions: 2%owf; LR 1:50; pH=4.2].

In order to investigate the mechanism of dyeing of untreated and pre-treated polyester fabrics with DR167, an intra-particle diffusion based mechanism has been studied. The plot of q_t vs. $t^{1/2}$ is shown in Figure 6 a, b.

According to Eq. 4, the intra-particle diffusion rate constant k_p and C are given in Table 1. If intra-particle diffusion is only involved in the adsorption process, then the plot will result in a linear relationship, passing through the origin; if not, the boundary layer diffusion controlled the adsorption to some degree (Cheung et al., 2007). As seen in Figure. 5a, b, the plots were firmly linear over the whole time range but with slightly deviation from the origin; this indicates that the intra-particle diffusion is not only the rate controlling step, but also some other processes may control the rate of dye adsorption (Kousha et al., 2012). The value obtained from the intercept gives an indication of the thickness of the boundary layer. The larger C shows greater boundary layer effect (Kismir & Aroguz, 2011). The values of C are demonstrated in table 1 over the whole temperature range, and this indicates that boundary layer effect may slightly control the dyeing rate.

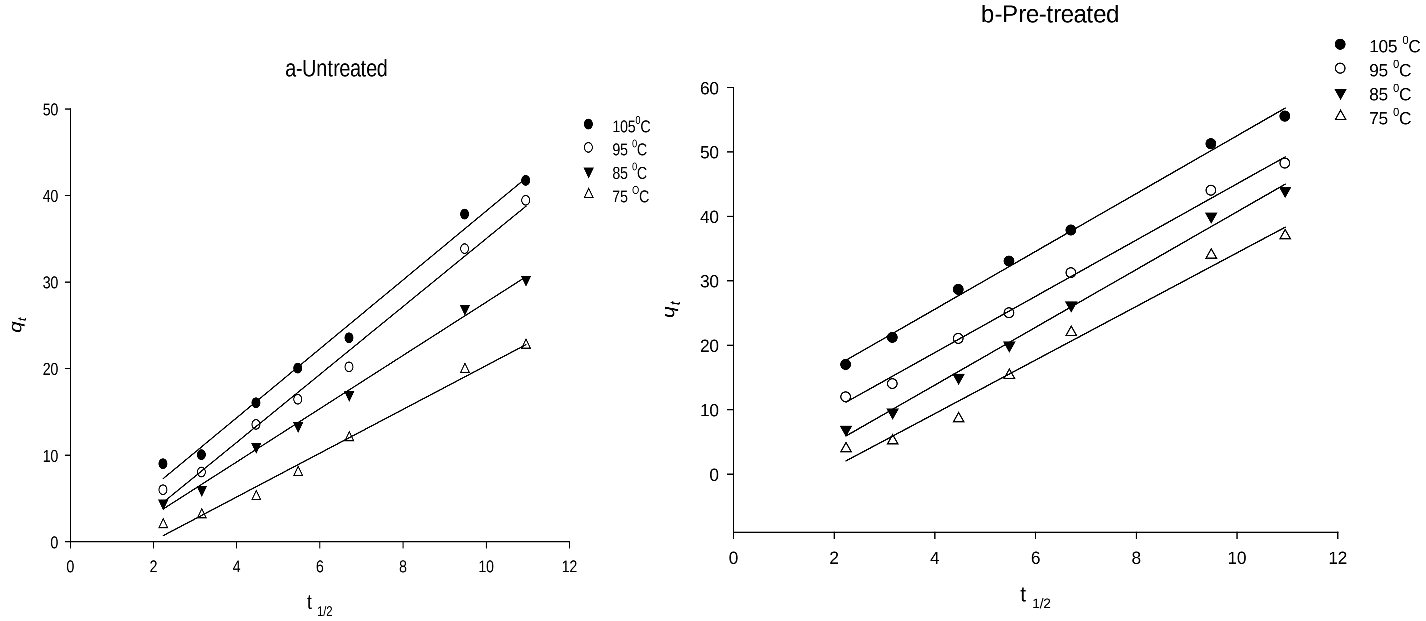

Figure 6. Intra-particle diffusion kinetics of of DR167onto a) untreated polyester b) pretreated polyester-fabrics at various temperatures. [Dyeing conditions: 2%owf; LR 1:50; pH=4.2].

The dyeing process is a solid/liquid phase process, which proceeds by the movement of the dye molecules from liquid phase to the solid surface of the fabric by virtue of their affinity, and then diffusion takes place inside the fabric. Therefore, the first process would be a fast adsorption controlled process where the dye molecules get into the fabric, the second slow process which is diffusion controlled, starts to take place (Weigmann et al., 1977). According to Hill's equation, Eq. 5, the diffusion coefficients were calculated. As can be seen from the data in Table 2, as the temperature of dyeing increases, the diffusion coefficient also increases which reflects the capability of fabrics to hold dye molecules within its polymeric matrix at higher temperatures. Also, the diffusion coefficients of DR167 onto untreated polyester- fabric are lower than that of DR167 onto pre- treated polyester -fabrics for all temperature range. Because of the rule of ZnO nano powder, the dye can easily diffuse and incorporate into the swelled polymeric matrix of fabrics in addition to the surface adsorption.

The activation energy of diffusion of DR167 onto untreated and pre-treated polyester -fabrics was calculated by Eq. 6 from the linear relationship of ln D against 1/T for both fabrics, Figure 7. The activation energy of the diffusion, explains the dependence of diffusion coefficient on the dyeing temperature and also represents the energy barrier that a dye molecule should overcome to diffuse into the fabric polymer chains (Alan, 1989 ; Kim et al., 2005). The activation energy of diffusion of DR167 onto untreated polyester -fabric (26.81 $kJmol^{-1}$) is significantly higher than that of DR167 onto pre-treated polyester fabric (21.89 $kJmol^{-1}$). This means that the activation energy of diffusion of DR167 is lowered by 18.35% for pre-treated polyester fabric. The magnitude of activation energy gives an idea about the type of adsorption which is mainly physical or chemical. The physisorption processes usually have energies in the range of 5–40 kJ mol^{-1}, while higher activation energies (40–800 kJ mol^{-1}) suggest chemisorption (Nollet et al., 2003) The diffusion coefficient and activation energy results for dyeing of both types of polyester fabrics using DR167 are demonstrated in Table 2. Considering these values are in the typical activation energy range for physisorption, one can conclude that DR167adsorbed onto untreated and pre- treated polyester -fabrics are mainly physical.

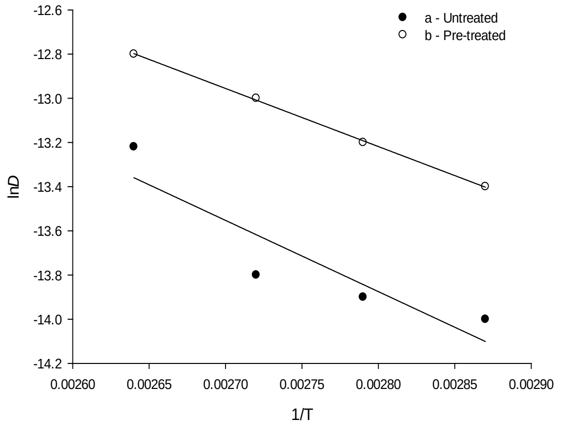

Figure 7. Relation between ln *D* and 1/T for determination of activation energy of dye diffusion onto (a) untreated polyester, (b) pre-treated polyester-fabrics

Table 2. Diffusion coefficients and diffusion activation energy of DR167 onto untreated and pre-treated polyester- fabrics at various temperatures

Fabric	**Temp. ^{0}C**	**D x 10^7 (cm^2 sec^{-1})**	**E_D (k J mol^{-1})**
Untreated	75	8.31	26.81
	85	9.19	
	95	10.25	
	105	18.51	
Pre-treated	75	15.15	21.89
	85	18.51	
	95	22.60	
	105	27.61	

3.4. Dyeing Thermodynamics

The thermodynamic parameters are depicted in Table 3. The data in the table shows that as the temperature increases, the partition coefficient of dye increases for both untreated and pre-treated polyester fabrics. This indicates again that the adsorption of dye towards untreated and pre- treated-polyester fabrics is well known as an endothermic reaction process. The most basic thermodynamic parameter is the standard affinity, $-\Delta\mu^0$ of the dye in dyeing solution towards fiber substrate. This parameter was defined as a difference between the chemical potential of the dye in the fiber and the chemical potential of the dye in the dyeing solution. This value measures the tendency of the dye to move from its standard state of the solution to its standard state of the fiber (Vickerstaff, 1954). From Table 3, it was noticed that the differences between the standard affinity of dye molecules towards untreated and pre-treated polyester fabrics are due to the differences in the chemical structures and physical properties of fabrics. Also, significant increases in the standard affinity values of DR167 onto pre-treated polyester fabric than that of DR167 onto untreated fabric were noticed.

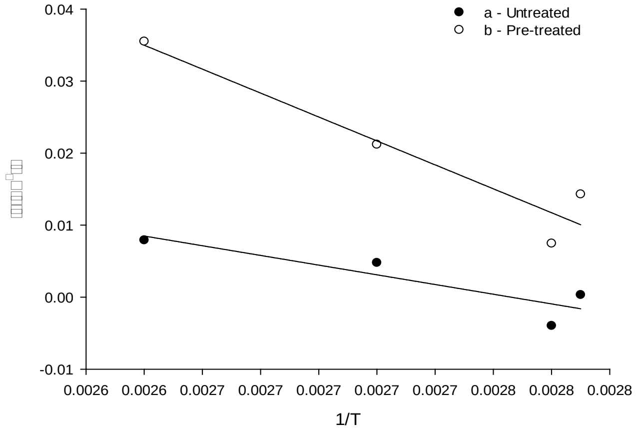

Figure 8. Variation of($\Delta\mu^0$/T) with (1/T) for estimation the enthalpy of DR176 onto (a) untreated and (b) pre-treated polyester fabrics

The enthalpy change, ΔH^0, means the amount of the released or absorbed thermal energy when the dye molecules are adsorbed onto fabric. In addition, the enthalpy change is considered as the measure of the adsorption strength of dyes (Wiley & Sons, 1984). Adsorption process can be classified as physical adsorption and chemisorption by the magnitude of the enthalpy change. It is accepted that if magnitude of enthalpy change is less than 84 kJ mol^{-1}, the adsorption process is physical in nature. However, the chemisorption process takes place in range from 84 to 420 kJmol^{-1} (Jeyasubramaniana et al., 2015). As can be seen from Figure 8, the enthalpy changes, ΔH^0, were determined as 67.31kJ mol^{-1} for AR167 onto untreated polyester while its corresponding value onto pre-treated polyester -fabric was 16.61 kJ mol^{-1}. All magnitudes of enthalpy change indicate that the adsorption is physical in nature. In addition to the enthalpy change had a positive value that confirmed again the endothermic nature of the overall dyeing processes.

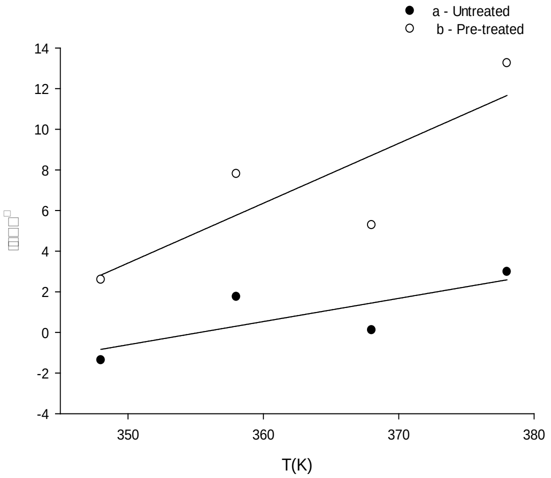

Figure 9. Variation of ($\Delta\mu^0$) with different temperatures for estimation the entropy of DR176 onto (a) untreated and (b) pre-treated polyester fabrics

Meanwhile, the entropy change, ΔS^0, shows the extent of the reduced freedom of dye molecules after the completion of dyeing and represents the entropy difference of the dye molecules within the fiber (Kim et al., 2007). According to Figure 9, the values of entropy changes are -0.773 and -1.95 for DR167 onto untreated and pre-treated-polyester fabrics, respectively. The decrease in the entropy values may explain the decrease in randomness after the dyeing process, Table 3. The entropy change shows negative values in dying process, because adsorbed dyes become more ordered within fiber molecules than the dyes in solution. Therefore, the value of the entropy change can be regarded as the measure of immobility of dyes within the fiber (Kongkachuichay et al., 2002; Alkan, 2004).

Table 3: Thermodynamic parameters for adsorption of DR176 onto untreated and pre-treated polyester fabrics at different temperatures.

Fabrics	**Temp.^{0} C**	**Temp.^{0} K**	**1/T**	**K partition coef.**	**$-\Delta\mu^O$ (kJ mol^{-1})**	**ΔH^O (kJ mol^{-1})**	**ΔS^O (kJ mol^{-1} K^{-1})**
Untreated	75	348	0.00287	0.62	-1.38	67.31	-0.773
	85	358	0.00279	1.04	0.116		
	95	368	0.00272	1.78	1.76		
	105	378	0.00264	2.59	2.99		
Pre-treated	75	348	0.00287	2.46	2.60	16.61	-1.95
	85	358	0.00279	5.92	5.20		
	95	368	0.00272	12.85	7.81		
	105	378	0.00264	67.96	13.26		

4. Conclusion:

Comparing the results, the dyeing of pre-treated and untreated polyester fabrics with DR167 at different temperatures can be regarded as an eco-friendly alternative to traditional dyeing without adding polluting auxiliary agents. For example, at 105C^0 the exhaustion values for untreated polyester and pre-treated polyester- fabrics are 72.20 and 98.55%, respectively; while at 75°C, the exhaustion values are 38.40% and 72.10% using DR167, respectively. The positive effect of dyeing process was investigated by the evaluation of some kinetic parameters and confirmed by saving 18.35 % activation energies for pre-treated fabric. In conclusion, the dyeing process is determined to be endothermic with a physical nature which further supported by the partition coefficient and standard affinity trends and the positive values of the enthalpy change.

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