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RESEARCH ARTICLE

Optimizing Dyeing Parameters of Remazol Golden Yellow G Dye upon Cotton Fabric

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Abstract

Herein, the effects of dyeing parameters such as temperature, concentration of salt, concentration of alkali, and duration of dyeing time of Remazol golden yellow G reactive dye upon cotton fabric were studied. It was found that implementation of the optimized parameters increased the percentage of dye exhaustion (%E) by 12.29% compared to conventional dyeing method. The effect of poor quality of water on the dye-fiber fixation was also assessed. It was found that the percentage of dye exhaustion decreased by 7.4% when untreated water was applied for the dyeing bath solution preparation. UV-Vis spectrophotometer was used for dye exhaustion measurements. It is demonstrated that the %E increased from 58.26% (using conventional reaction parameters) to 70.91% by combining optimized dyeing parameters (temperature of 60 ^{o}c, 50 g/L of NaCl, 10 g/L of NaOH, and 80 minutes of dyeing time). Wash fastness measurements were also carried out using Launder-o-meter. A constant liquor ratio of 1: 50 and depth of shade 5% were used throughout this study.

INTRODUCTION

Reactive dyes are colored compounds that contain functional groups capable of forming covalent bonds with active sites in the fiber such as hydroxyl groups in cellulose (cotton), amino, thiol, and hydroxyl groups in wool, amino groups in polyamides, etc.[1, 2] Reactive dyes are characterized by nitrogen-to-nitrogen double bonds (azo bonds (N=N).[3] The color of these dyes is associated with the azo group and related chromophores.[3] Dyeing of cotton fabric with reactive dyes have several advantages with respect to the achievable high degree of wash fastness and color brilliance in the process of dyeing and a wide shade range over other textile dyes.[4] For this reason, they are the dominant choices of colorants for dyeing of cotton fibers. However; dyeing with reactive dyes is highly susceptible to larger degree of hydrolysis of the vinyl group due to reaction with water (the solvent).[3, 5] In practical dyeing, therefore it is necessary to adopt proper dyeing parameters.

On the other hand, some studies demonstrate salt free dyeing of cotton fabric using cationization of the fabric.[6, 7] However, the majority of chemicals used for introducing cationic sites in cotton are themselves not safe for the environment. Hence, this report tried to compensate the trade-off between high environmental impact and poor dye-fiber fixation using optimum dyeing parameters. The present study is carried out aiming to enhance reactive dye uptake of cotton fabric by optimizing dyeing parameters at Bahir Dar Textile Share Company, Ethiopia. Although conventional dyeing procedures have been used in the factory, they are still suffering from low dye uptake. Herein, we investigated the optimum dyeing parameters such as temperature, amount of alkali (pH of reaction bath), amount of salt (NaCl), and dyeing time of reactive golden yellow G dye upon cotton fabric. The effect of poor quality of water on the adsorption of dye has also been examined quantitatively. In this study we use bleached and mercerized

100% cotton fabric and commercial remazol golden yellow G reactive dye. The dyeing process was performed at 5% shade and 1: 50 liquor ratio in exhaust process. The chemical structure of remazol golden yellow G reactive dye is depicted in Figure 1 and its properties are illustrated in Table 1.

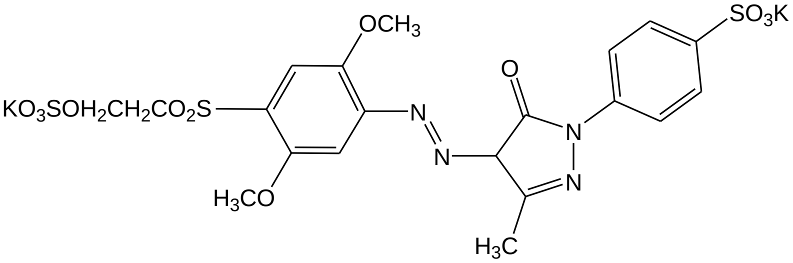

Figure 1. The chemical structure of remazol golden yellow G reactive dye (Reactive Yellow-17).

Table 1. Some characteristics of remazol golden yellow G dye.

Characteristics	Remazol golden yellow G
Molecular formula	$C_{20}H_{20}K_2N_4O_{12}S_3$
Color index name	Reactive Yellow-17
Formula weight	682.77 g/mol
λ_{max}	595 nm
Class	Diazo (–N=N– bond)

EXPERIMENTAL

Materials: Bleached and mercerized 100% cotton fabric was used in this work. Laundr-o-meter was used for wash fastness test measurements. Commercial grade remazol golden yellow G (RGY) reactive dye was used throughout this study as it was received.

Dyeing procedure: The conventional process of dyeing of cotton fabric with remazol golden yellow G dye was performed at 5% shade and 1: 50 liquor ratio in exhaust process. The fabric was bathed inside the dyeing solution at room temperature followed by addition of 30 g/L of NaCl. In the mean time the temperature was kept at 25 ^{o}C and the dyeing process was continued for 30 minutes. Then 20 g/L of NaOH was added to the dyeing bath and stayed for additional 30 minutes. The final dyed fabric was neutralized with 2.5 g/L of acetic acid followed by rinsing with excess water until the final rinse become colorless. To determine the optimum dyeing parameters, we start with the conventional dyeing procedure. Then we took range of values of each fixation parameters at a specific liquor ratio (1: 50) and depth of shade (5%). Dyeing was sequentially done at variable values of one parameter by measuring the percentage of dye exhaustion (%E) in the given range of values keeping the rest parameters at their conventional value. The remaining dyeing parameters have been determined in similar way. Table 2 summarizes the range of values of each parameter.

Table 2. Ranges of values of dyeing parameters at 1:50 liquor ratio and 5% depth of shade.

Temperature (^{o}c)	Amount of NaOH (g/L)	Amount of NaCl (g/L)	Dyeing time (min)
40	5	20	50
50	10	30	60
60	15	40	70
70	20	50	80
80	25	60	90

Determination of dye exhaustion: Exhaustion is the total amount of dye taken up by cotton fabric. It was determined by measuring the optical absorbance of the dye bath before and after dyeing process. The absorbance of diluted dye solution was measured at the wavelength of maximum absorption (λ_{max} = 595 nm) using UV/Vis spectrophotometer.[8, 9] Maximum absorption (λ_{max}) of the dye was determined from the calibration curve of series of standard solutions. First stock solution (1 g/L) of dye sample was prepared. Then a series of standard solutions with a concentration range of 0.01 g/L to 0.08 g/L were prepared by appropriate dilution. The percentage of dye exhaustion (%E) was then calculated using the following equation:[10]

$$\%E = 100 \times \left(1 - \frac{A_1}{A_o}\right) \ldots\ldots\ldots\ldots \quad (1)$$

Where A_o and A_1 are the absorbances of the dye solution before and after the dyeing process respectively.

Wash fastness test: ISO Test No. 3 (ISO C01–C06) method was employed for wash fastness test.[11] A specimen of 10 x 4 cm dyed cotton fabric was sandwiched between undyed cotton fabric and viscose fabric and sewn along all four sides to form a composite specimen. Washing solution containing 5 g/L soap and 2 g/L sodium carbonate was taken in to Launder-o-meter. The specimen was treated for 30 minutes at 60 ± 2 °c at a speed of 40 rpm. Then it was removed and rinsed twice in cold water. The stitch was opened on three sides and dried in shadow. The change in color and degree of staining was evaluated using geometric gray scales.

RESULTS AND DISCUSSION

A straight line passing through the origin was obtained for the calibration graphs plotted at the wave length of maximum absorbance (λ_{max}=595nm) for the confirmation of Beer-Lambert's law. The linear nature of the plot of absorbance against dye concentration (Figure1) indicated that the remazol golden yellow G dye obeyed the Beer-Lambert's law:[8, 9, 12, 13] Mathematically, Beer-Lambert law is expressed as:

$$A = \varepsilon c l \ldots\ldots\ldots\ldots \quad (2)$$

Where *A* is the absorbance or optical density, *c* is the concentration of solute (dye) in solution, *l* is the path length of radiation through the sample in centimeters (1cm) and *ε* the molar absorptivity or extinction coefficient.

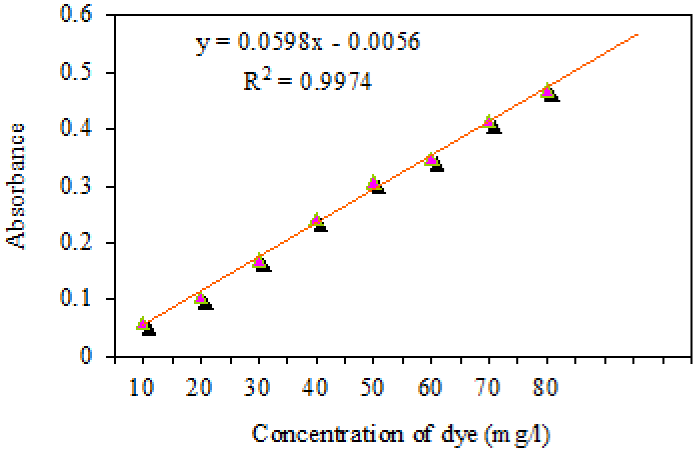

Figure 2. Calibration curve of remazol golden yellow G dye

To determine the optimum dye-fixation parameters we assess the effect of each parameter at variable values. At these various parameter values the percentage of dye exhaustion was measured and the results are presented in Figure 3 and 4. The effect of dyeing temperature was studied by varying the reaction temperature from 40 °c to 80 °c while keeping the amount of sodium hydroxide at 20 g/L, the amount of sodium chloride at 30 g/L, and the reaction time for 60 minute. Figure 3 illustrates the percentage of dye exhaustion obtained at different temperatures. It is anticipated that the percentage of dye uptake onto cotton fabric increases with increasing of the reaction temperature and reaches maximum at 60 °c and decreases. It has been reported that the maximum dye uptake (adsorbed on the fabric) or the reactivity of the dye with cel1ulose of the fabric is affected by temperature and molecular structure of the dye.[14] We have found that the amount of the dye adsorbed on the fabric physically or chemically was lower at low temperature range. There are two possible reasons for this. First, suitably higher temperature (60 °c in this particular case) increases the kinetic energy of the dye molecules and thereby enhances the rate of penetration of dye in to the vicinity of the substrate. In other words, the increase in temperature increases the molecular vibrations both in the fiber and dye, which induces favorable fixation kinetics. Second, the affinity of the reactive dyes with triazine rings for cotton fabric decreases with a significant rise in temperature because of smaller molecular weight and non-co-planarity of the dyes in comparison with direct dyes. Further investigations are necessary to consider the effect of the molecular structures on the reactivity of the dyes and collu1ose.

Salt (usually NaCl) increases dye exhaustion by enhancing the attraction between the dye molecule and the fabric. Usually reactive dye molecules have negative charges and the cotton fabric also acquires negative charge on its surface in aqueous medium thus repels negatively charged dye during the dyeing process.[5, 15] Such repulsion between fiber and dye is offset by using appropriate amount of salt in the dye bath so as to improve exhaustion. To determine the appropriate amount of NaCl, we employed various amounts of NaCl salt that range from 20 g/L to 60 g/L. The other parameters are kept constant, at 60 °c reaction temperature (pre-optimized), at 20 g/L sodium hydroxide, and for 60 minute reaction time. The %E increased with increasing the amount of NaCl and reached maximum value at 50 g/L amount of salt. It is evident from the Figure 3(b) that 50 g/L of NaCl salt is the appropriate amount that results in highest %E at the given liquor ratio (1: 50) and % shade (5%). At lower concentrations of salt, an increase in the rate and extent of %E was shown, which is because of the formation of an electrophilic layer on the cellulose fiber that attracts the nucleophilic group of the reactive dye. Increasing the amount of NaCl beyond 50 g/L results in low %E value. This might be associated with the formation of more positive ions in the reaction bath, which leads to high solubility and migration of the dye from the fabric. On the other hand, some studies demonstrated salt free dyeing of cotton fabric using cationization of the fabric itself so that the dye will be migrated to the fabric and fixed without any addition of salt to the dyeing bath. However majority of the chemicals used for introducing cationic sites in cotton fabric are themselves not safe for the environment. Hence, this report tried to compensate the trade-off by using lower amount of salt with better dye fiber fixation and lower environmental impact.

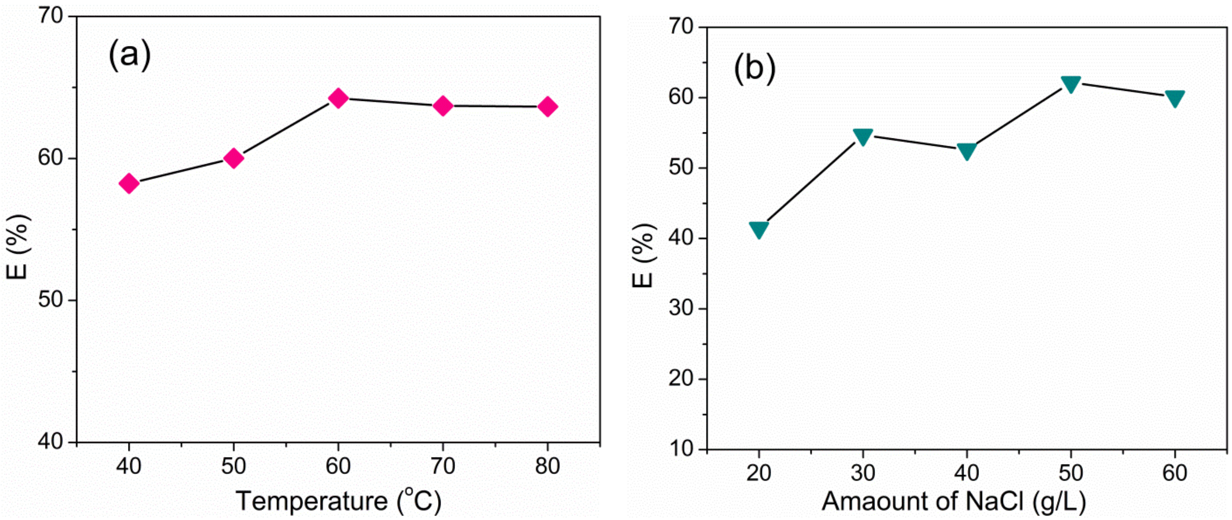

Figure 3. %Exhaustion at (a) different reaction temperatures, (b) different amount of salt (NaCl).

Fiber reactive dyes react with the cellulosic fiber in the presence of alkali to form a strong covalent chemical bond between carbon atom of the dye molecule and oxygen atom of the hydroxyl group in the cellulose.[10] The nucleophilic cellulose-O^- moiety formed after the addition of alkali (NaOH) can undergo substitution reactions with chlorotriazine type structures, and nucleophilic addition reaction with the vinyl sulphone type dyes. Based on this premises, we found it important to determine the amount of NaOH which can result better dye-fiber fixation. To do so, a series of solutions with different amount of NaOH, which ranges from 5 g/L to 25g/L, were prepared.

Temperature, amount of sodium chloride, and reaction time were kept constant at 60 ^{o}c (pre-determined), 50 g/L (pre-determined) and 60 minute respectively. It is depicted from Figure 4(a) that the maximum %E was observed at the 10 g/L amount. The reaction mechanism is shown below. [4]

$$\underset{\mathrm{I}}{\mathrm{RSO_2CH_2CH_2OSO_3Na}} \xrightarrow{\mathrm{OH^-}} \underset{\mathrm{II}}{\mathrm{RSO_2CH{=}CH_2}} \xrightarrow{\mathrm{OH^-}} \underset{\mathrm{III}}{\mathrm{RSO_2CH_2CH_2OH}}$$

When the amount of alkali increased to a certain value (10 g/L, in this particular case) the rate of generation of vinyl sulphone group (**II**) of the reactive dye from its sulphonium salt (**I**) precursor was increased. As a result of this the better dye-fabric fixation was observed (higher %E value). Once the amount of NaOH has increased beyond 10 g/L, the dye-fabre fixation became reduced (lower %E value). This might be due to the change of the vinyl sulphone group to hydoxyethylsulphone group (**III**). Moreover, at higher concentration of alkali the fiber surface become highly negativly charged which results in repulsion of the same charged dye molecules.

The effect of reaction time is another vital parameter that must be considered during dyeing of cotton fabric with reactive dyes. A certain reasonable time permits a mass transport from a liquid medium to the fabric surface without temperature increase. Similarly, in dyeing processes, transport of dyes from a solution to the fiber surface and further into its interior structure depends mainly on time, in addition to other factors. In this particular case, five different dyeing durations, from 50 min to 90 min, have been considered at constant amount of salt (50 g/L), temperature (60 ^{o}c) and amount of alkali (10 g/L). The effect of reaction time on %E is shown in Figure 4(b). The results show that under the given dyeing parameters of salt, temperature and amount of alkali 80 minutes of dyeing time results the highest %E performance. Even though the time needed depends on some factors like the degree of agitation of the bath, the liquor ratio, the type and construction of the material, the dye bath temperature and pH; the results obtained revealed that increasing time of dyeing increases percentage of dye exhaustion. This is because of appropriate time for adsorption and fixation of dye from the solution to the fabric. Increasing the time above these limits seems to favor the hydrolysis of dye and showed slight decrease in %E.

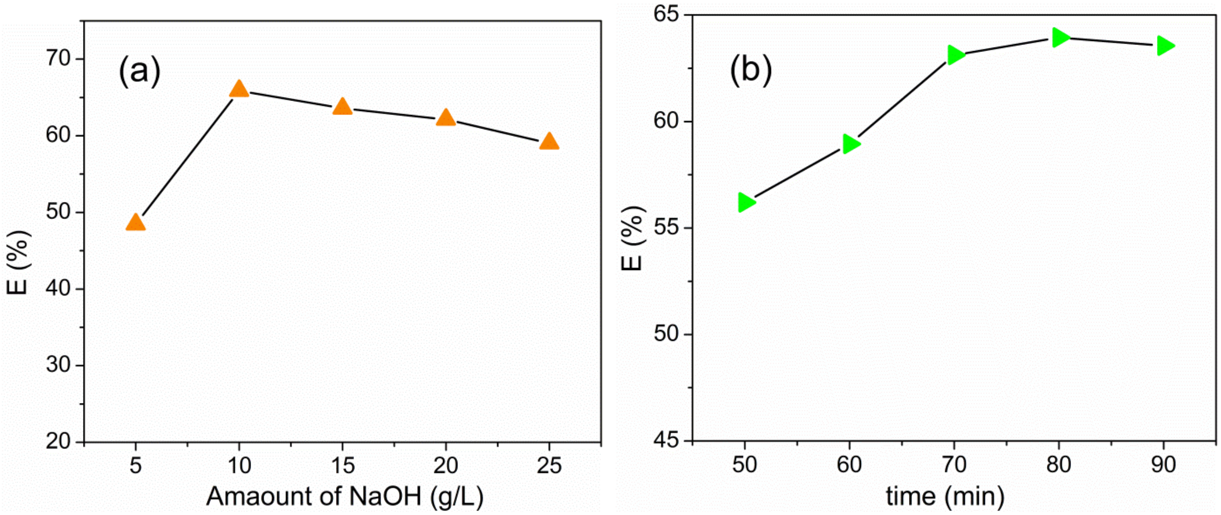

Figure 4. %Exhaustion at (a) different amount of alkali (NaOH). (b) different time of dyeing.

The optimized values of the above four parameters at which the %E was maximum have been taken and combined to examine a modified procedure. Using this optimized procedure, %E was determined and the result was found to be 70.91%. Compared to the conventional dyeing procedure, whose %E value is 58.62%, the synergetic effect the optimized parameters result in better dye-fiber fixation. The value of each optimized fixation parameters is presented in Table 3.

Table 3. Comparison of conventional and optimized dyeing parameters

Method	Temperature (^{o}c)	NaCl (g/L)	NaOH (g/L)	time (min)	dye (g/L)	Mass of fabric (g/L)	E (%)
Conventional dyeing	25	30	20	60	1	20	58.62
Optimized dyeing	60	50	10	80	1	20	70.91

Liquor ratio= 1: 50; Depth of shade= 5%

In this study, for conversional type of dyeing we use tap water directly used without any physical and chemical treatments (the same as the company is doing). For comparison we use distilled water (DI) to prepare the dyeing bath solution. The %E was then determined using the previously optimized dyeing parameters. The %E was found to be 65.68 and 70.91% for dyeing with untreated water and DI water respectively. The results showed that, dyeing with untreated river water decreases the percentage of dye uptake by 7.4%. The decrease in %E might be associated with the presence of cationic and anionic impurities, heavy metals and dust particles that interfere and/or compete with dye adsorption in to the fiber, ending up with poor dye-fiber fixation. Therefore this study showed that, for better dye-fiber fixation appropriate chemical and physical water treatment activities should be done prior to the dyeing process.

It is worth mentioning that, for a colored fabric to be commercially viable, wash fastness test measurement is critical. Herein, we perform the wash fastness test for range of values of dyeing parameters and the results are presented in Table 4. The ratings are based on the staining of bleached cotton fabric using multi-fiber test strips. For this test, most of the samples show gray scale ratings of 4.5 or 5. However, the samples dyed at 60 g/L concentration of salt and a temperature of 40 ^{o}c showed rating of 4. A lower rating value (3.5) was obtained for the fabric dyed at 5 g/L alkali concentration. This might be due to weak dye-fiber bonding at very low concentration of alkali. Because at low concentration of alkali, the extent of formation of nucleophilic cellulose-O^- moiety of the cotton fabric is low, this ends up with low degree of nucleophilic addition reaction with the vinyl sulphone reactive dye. The wash fastness test of the samples dyed using distilled water and untreated water solvents was also measured. Both samples showed a rating value of 5 from the gray scale.

Table 4. Wash fastness test measurements obtained from gray scale ratings.

Temperature (^{o}c)		Amount of salt (g/L)		Amount of alkali (g/L)		Dyeing time (min)	
Range	Fastness	Range	Fastness	Range	Fastness	Range	Fastness
40	4	20	4.5	5	3.5	50	5
50	4.5	30	5	10	5	60	5
60	5	40	5	15	5	70	5
70	5	50	5	20	5	80	5
80	5	60	4	25	4.5	90	5

CONCLUSION

In this study, the appropriate dyeing parameters such as temperature, amount of NaCl, amount of NaOH, and duration of dyeing time have been optimized at a 1: 50 liquor ratio and 5% shade. The experiment was carried out using bleached and mercerized 100% cotton fabric with vinyl sulphone golden yellow G (RGY) reactive dye. UV-Vis spectrophotometer has been employed to determine the percentage of dye exhaustion. The results showed that, the highest dye exhaustion took place better in the reaction temperature of 60 ^{o}c, 10 g/L of sodium hydroxide, 50 g/L of sodium chloride and 80 minutes of dyeing time. By combining these optimized parameters together, the %E was increased to 70.91% which showed an appreciable increase when compared with the value obtained from the conventional dye bath i. e. 58.26%. In addition to this, the effect of poor quality of water on the dyeing-fiber fixation characteristics was also assessed. We have found that dyeing with untreated water decreases the percentage of dye exhaustion by 7.4%. The decrease in %E might be associated with the presence of cationic and anionic impurities, heavy metals and dust particles that interfere and/or compete with dye adsorption in to the fiber, ending up with poor dye-fabric fixation. Textile industries are in the first line among other industries that use huge amount of raw materials. Hence, serious attention must be given on implementing procedures with possible optimized parameters to minimize unnecessary lose of resources. On this premise, this study played a vital role on minimizing unnecessary dye lose and on enhancing dye-fiber fixation. The procedure can be scale-up to other similar reactive dyes up on cotton fabric with minor modifications.

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