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Influence of Process Parameters on Exhaustion, Fixation and Color Strength in Dyeing of Cellulose Fiber with Reactive Dye

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Abstract

In this study, Cotton plain woven fabric was dyed with Reactive Red 195 by exhaust dyeing method. The influences of different process parameters such as electrolyte (salt), alkali (soda), liquor ratio (M:L), dyeing time, dyeing temperature and pH on exhaustion percentage, fixation percentage and color strength (K/S) were studied. In order to study the effects of one factor, that specific factor was changed without changing the other parameters. The photo-sensitivity of dye solution before dyeing, after dyeing and after soaping was determined by UV-Vis Spectroscopy at λ_{max} and the color strength (K/S) value of the dyed samples was measured by using reflection spectrophotometer. The calibration curve of Reactive Red 195 was studied and the dye concentration was determined using the calibration curve of Reactive Red 195. The exhaustion and fixation of dyes on the cotton fabric were calculated by the absorbance method. The results show that the exhaustion, fixation and K/S value of the Reactive Red 195 on cotton were positively correlated with the increase of salt, alkali, temperature, time and pH value. With the increase of liquor ratio, there was a significant negative correlation on exhaustion, fixation and K/S value. The optimum process parameters of Reactive Red 195 were determined by using the orthogonal experiment. It was observed that the electrolyte and alkali concentration had a great influence on dye exhaustion and fixation,

Keywords: Reactive Dye, Cellulose Fiber, Dyeing Parameters, Exhaustion, Fixation, Color Strength (K/S)

Introduction

In recent years, with the progress of people's living standards and the enhancement of environmental awareness, cotton fiber is favored by people for its comfort, renewability, and biodegradability. Cotton is the most important natural textile fiber in the world, which is used to produce clothing, home furnishing, and other protective clothing. Cotton is the perfect type of regenerated cellulose fiber [1] and reactive dyes are the most important dyes in cellulose fibers dyeing and printing. Reactive dyes have the advantages of bright color, good color fastness, and simple application process [1-5]. Reactive dyes can react with fiber to form a covalent bond between fiber and dye. Covalent bonds are formed between dye molecules and -OH groups of cellulose fibers and become an important part of it. This covalent bond is a strong chemical bond. The formation of the covalent bond between fiber and dye depends on different dyeing factors, such as concentration of electrolyte (salt), concentration of alkali (soda), liquor ratio, dyeing time, dyeing temperature and pH value. Generally, the exhaustion of reactive dyes depends on the concentration of electrolyte to a great extent, and the dye reactivity increases with the increase of dyeing temperature and alkali concentration. Dyeing can be divided into two steps: exhaustion of dyes on the substrate and chemical reaction (fixation) between dyes and cellulose anions. When the fiber is immersed in water, the surface shows negative ions. The retention rate of dye anions and cotton fibers anions is higher. As a result, there would be no reaction between the dye and the fiber. To solve this problem, salt is used to disperse the charge density. Salt is ionized to form cation and anion. The dye anions easily react with cellulose anion replacing Na^+cation in the neutral state [3, 4].

$$NaCl \longrightarrow Na^+ + Cl^-$$
$$Na_2SO_4 \longrightarrow 2Na^+ + SO^{-2}$$
$$Cell{-}OH \longrightarrow Cell{-}O^- + H^+$$
$$Cell{-}O^- + Na^+ \longrightarrow Cell{-}ONa$$

Salt plays an obligatory role as electrolyte and salt is used as an exhausted agent in reactive dyeing of cellulose fiber. On the contrary, dye fixation can be carried out in the presence of alkali. Due to the addition of alkali, the dye migrates from outside of the fiber to the inside of fiber and form a covalent bond with the fiber. Therefore, electrolytes and alkali are two basic auxiliaries of reactive dyeing, which contribute to the exhaustion and fixation of dyes. Again the dye exhaustion and fixation rate vary with the change of liquor ratio, dyeing time, dyeing temperature and pH value. In this study cotton fabric was dyed with Reactive Red 195 an azo dye (N=N) which has two reactive groups i.e. triazine (MCT) and vinyl sulphone (VS) is shown in Figure 1. Reactive Red 195 (MCT-VS azo dye) is one of the most versatile classes of dye widely used in cellulose fiber dyeing and can offer bright shade and good fastness properties in case of cotton fiber dyeing.

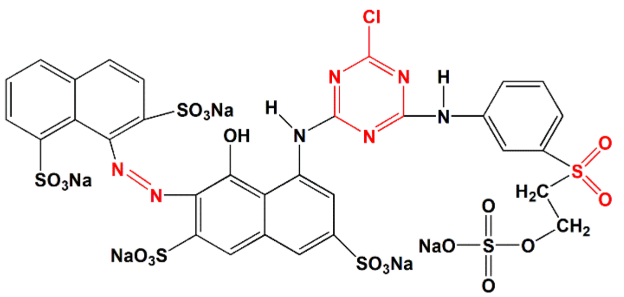

Figure 1: Chemical structure of Reactive Red 195.

Taguchi experimental design, commonly known as an orthogonal array (OA), consists of a group of component factor designs, ignoring interactions and focusing on the assessment of leading effects. Taguchi's method reduces changes in the method done by the strong intention of experiments. The main principle of Taguchi design is to decrease the variance of the test and determine the optimum environment of the process by using OA. The Taguchi technique was developed by Genichi Taguchi [6]. He developed a design of experiment (DOE) to find how dissimilar factors affect the variance and mean of the process performance characteristics, which define the function of the process. Taguchi's experimental design includes the implementation of orthogonal arrays establishing the factors affecting the method and the level at which they may be changed. The Taguchi method does not necessarily test entirely potential combinations like the factorial design but paired combinations. This allows the collection of necessary data to determine which elements have the highest impact on product quality with the least number of experiments, thus saving time and resources. Three different classes of proficiency features were commonly applied in the Taguchi OA such as the higher is the better, the minimal is the better, and the lower is the better.

Some researchers have already studied the influences of different dyeing parameters on reactive dyeing of cotton individually [7-10] such as Abu Naser Md. Ahsanul Haque worked on the effect of salt, alkali, liquor ratio and temperature on color strength in reactive dyeing of cotton [8] and Md. Eman Talukder worked on effects of salt concentration on the dyeing of various cotton fabrics with reactive dyes [9]. In this study, the influences of six process parameters in reactive dyeing i.e. concentration of electrolyte (g/l), concentration of alkali (g/l), liquor ratio (M:L), dyeing time (min), dyeing temperature (℃), and dyeing pH were studied. As well as three responses such as exhaustion (%), fixation (%) and color strength (K/S) value were preferred to study the influences of each parameter in reactive dyeing of cotton fabric. Then, four factors and two responses were chosen to find out the optimum dyeing conditions for Reactive Red 195 using the Taguchi Orthogonal Array (OA).

Experimental

Materials and Instruments

Desized, scoured and bleached 100% cotton plain woven fabric (yarn count 40s×40s Ne, yarn density 150 × 200, fabric weight 140 g/m^2 was used as the raw material and purchased from Jiangnan Group Co., Ltd., China. Commercial grade Reactive Red 195 was collected from Hangzhou Tiankun Chem Co., Ltd. Other chemicals were used in the experiment (such as electrolyte, alkali, detergent, acetic acid, sodium perborate, ECE phosphate) were generally laboratory-grade substances. Infrared dyeing machine (Model HB-HWX24, Huibao Dyeing and Finishing Machinery Factory, Ronggui City, China) was used to dye the samples. The color strength (K/S) was measured by CHN-Spec CS-650A Spectrophotometer (Hangzhou Color Spectrum Technology Co. Ltd.) and the abs of the dye liquor were measured by PERSEE TU-1900 UV-Vis Spectroscopy.

Exhaust Dyeing

Exhaust dyeing method was carried out to dye the cotton fabric with Reactive Red 195 (1% o.w.f). Infrared sample dyeing machine and 5gm sample fabric were used. Different dyeing parameters, such as different electrolyte (NaCl) concentrations

(5, 10, 20, 30, 40, 50, 60, 70 g/l), different alkali (Na_2CO_3) concentrations (2, 4, 6, 8, 10, 12, 14, 16, 18, 20 g/l), different liquor ratios (1:05, 1:07, 1:10, 1:13, 1:15, 1:17, 1:20, 1:25, 1:30), different dyeing times (1, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 minutes), different dyeing temperatures (30, 40, 50, 60, 70, 80, 90℃), and different dyeing pH values (9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0) were used to dye the samples. In order to study the effect of a specific parameter, other parameters remain unchanged when the specific parameter changed. The general dyeing process curve is shown in Figure 2. After treatment; all dyed samples were cold washed at 40℃ for 10 min, then neutralized with 0.5 g/l acetic acid at 50℃ for 10 min, hot washed at 70℃ for 10 min, and then soap washed. The soaping process was completed in a soap solution containing 2 g/l non-ionic detergent, using a liquor ratio of 1:07 at 95℃ for 15 minutes. Then the dyed samples were rinsed, dried and characterized.

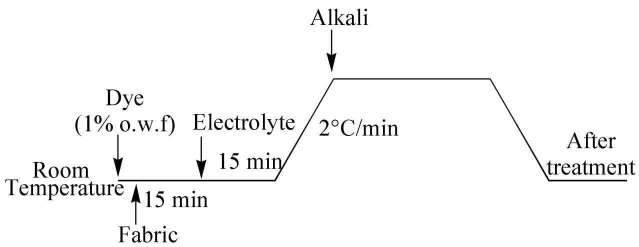

Figure 2: Dyeing process

Characterization and Measurement

UV-Vis Spectroscopy Analysis

PERSEE TU-1900 Ultraviolet-Visible Spectroscopy (UV-Vis) was used to calculate the absorbance value of the dye and soaping liquor. The visible spectrum of the dye solution was recorded to decide the maximum absorption wavelength (λ_{max}). The absorbance value was calculated between 380-700nm wavelengths and gave a λ_{max} value of 560nm. Firstly, a calibration plot of concentration versus absorbance was formed at the wavelength of maximum absorption by measuring the absorbance of dye solution with certain concentrations. According to the calibration curve of the dye in water, the concentration of the dye solution was determined and a linear relationship was found between absorbance and concentration, which is known as Beer-Lambert law [10-13]. For each dyed sample, the absorbance of the dye bath was calculated at the beginning of dyeing, at the end of dyeing and after the soap wash then diluted by using freshwater. The absorption value of the diluted solution was measured and then the exhaustion and fixation rate was calculated according to the calibration curve.

Dye Exhaustion and Fixation

The proportion of the amount of dyes adsorbed by the fibers after dyeing to the primary amount of dyes is called as the exhaustion rate (%E) of the dyes. Spectrophotometric analysis was used to decide the amount of dye in the dye bath. The absorbance of the dye solution before dyeing, after dyeing and soaping liquor was determined by Ultraviolet-Visible (UV-Vis) Spectrophotometry at the wavelength of maximum absorption (λ_{max}, 560nm) after adequate dilution (1:25). The concentration of the dye was determined according to the standard curve. The percentage of exhaustion was calculated from equation 1 [14, 15]. Dye fixation rate (%F) refers to the number of dyes chemically bonded to the fiber, which can be obtained by calculating the number of fixed and unfixed dyes bonded with the fiber and washed out by soaping process. The rate of fixation was determined after soaping. The washing solutions were collected and the absorbance of the soaping liquor was measured. The fixation (%F) percentage was calculated by using equation 2 [10, 16].

$$\mathrm{E}\ (\%) = \left(\frac{A_o - A_t}{A_o}\right) \times 100 \qquad (1)$$

$$\mathrm{F}\ (\%) = \left(\frac{A_o - A_t - A_s}{A_o}\right) \times 100 \qquad (2)$$

Where A_o, A_t and A_s are the absorbance of the initial dye bath, the dye bath at time point t (residual dye bath after dyeing) and the absorbance of the soaping liquor respectively at λ_{max}.

Measurement of Color Strength (K/S)

For recent colorimetric, color strength (K/S) value plays a crucial role. The surface color of the two dyed fabric can be compared by using the color strength (K/S) value. The determination of the color strength (K/S) value is simple and feasible. The color strength (K/S) value of dyed and soap washed fabrics was measured by a CHN Spec CS-650A Spectrophotometer at the wavelength of maximum absorbance. However, the calculation of the visible region is also used [17]. According to the reflectance readings at 560nm (λ_{max}), the color strength (K/S) value of the dyed samples was determined by the application of the Kubelka-Munk equation 3 [17, 18].

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \qquad (3)$$

Where S is the scattering coefficient, K is the absorption coefficient, R is the reflectance of the dyed sample at the wavelength of maximum absorption (λ_{max}). Kubelka-Munk equation was calculated by color matching software, and K/S value was directly output by spectrophotometer. Each sample was measured 10 times, the measurement points were changed randomly. A higher K/S value represents a more saturated color.

Measurement of Color Fastness Properties

Color fastness is an important quality parameter in the perspective of consumer's products and demand. The washing fastness identifies the loss and change of color during washing, as well as staining of color to other clothes. Washing fastness was carried out to determine the performances of dyed textiles in the regular washing process with detergents and additives. In this study, the ISO-105-CO6 test standard was used for measuring the washing fastness properties of the samples dyed with Reactive Red 195. The recipe consisted of Sodium Perborate 1 g/l, ECE phosphate 4 g/l. The washing process was done by using a washing fastness tester (SDL Atlas) and the machine was run at 60℃ for 30 minutes with 25 stainless steel balls. Rubbing fastness refers to the transfer of color from the surface of dyed textiles in case of friction. In order to study the dyed fabric's quality, both the wet and dry rubbing fastness tests were performed. The colorfastness to the rubbing was carried out according to ISO-105-X12 standard by using crock meter (Yuan More, Y571).

Results and Discussion

Absorbance Calibration Curve Analysis

The calibration curve of the absorbance and the dye concentration (Beer-Lambert law) was determined by a UV-Vis spectrophotometer. The results showed that there was a linear relationship between absorbance and concentration. In this study, the calibration curve was used to calculate the dye concentration. According to the calibration curve, the concentration of the unknown dye solution was determined. For complete accuracy, the unknown sample was operated as the standard sample in the equivalent matrix [11].

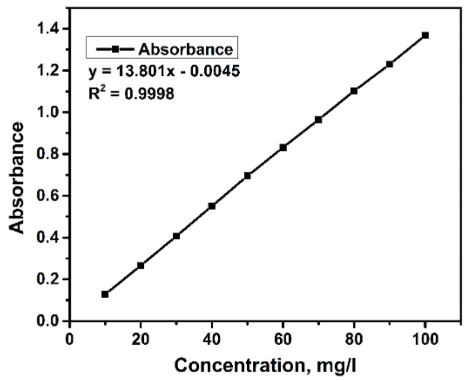

Figure 3: Calibration curve (Beer-Lambert calibration graph) of Reactive Red 195 at the λ_{max}

The calibration curve was linear and the concentration of dye could be calculated according to the fitting linear equation, y=13.801x-0.0045, where x and y are the concentration and absorbance respectively. The correlation coefficient (R^2) value was determined by linear regression analysis with a computer program and gave a $R^2 = 0.9998$ with high values of the correlation coefficients. The plot of absorbance against the concentration of dyes is represented in Figure 3.

Influence of Electrolyte (Salt) Concentration

Electrolyte helps in the dye exhaustion. The amount of electrolyte used was different in each experiment ranging from 5 to 70 g/l to observe the influence of electrolyte concentration on exhaustion, fixation and color strength (K/S) and to find out the optimum concentration of electrolyte. While the other parameters remained unchanged, such as the dyeing was carried out with dyes content 1% o.w.f and alkali content 10 g/l at a liquor ratio of 1:10. The dye bath was run for 30 minutes at the temperature 60℃ maintaining the dye bath pH value of 10.5. Figure 4 represents the influence of different electrolyte concentrations on exhaustion, fixation and K/S value (before and after soaping) of cotton dyed fabric. Here almost a similar kind of result was found, the exhaustion, fixation and K/S value were increased by increasing the amount of electrolyte. But the increasing rate of exhaustion, fixation and K/S became slower when the electrolyte content was more than 40 g/l. The increasing rate of exhaustion, fixation and K/S was very high until the concentration of electrolyte was 40 g/l and was sufficient to enable the dye molecules to migrate inter and intra-fiber pores of cellulose fiber from the dye bath. No significant difference was found in the use of higher concentrations of electrolyte, as the optimum amount of dye exhaustion, fixation and K/S was achieved by using 40 g/l salt content. However, when the salt content was lower than 40 g/l, the exhaustion, fixation and K/S values were decreased. So, in this study 40 g/l electrolyte concentration was selected as the optimum concentration for the subsequent dyeing process.

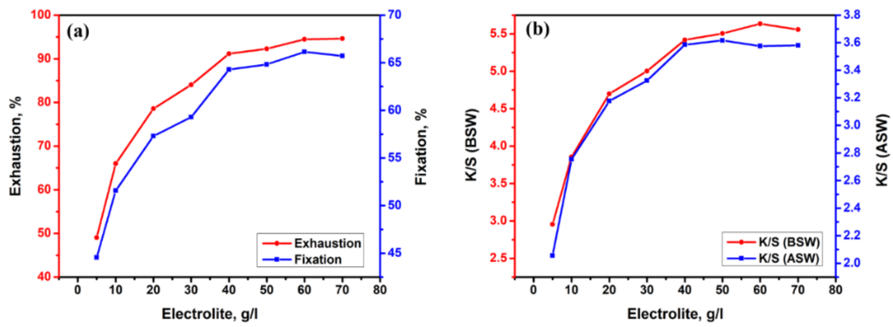

Figure 4: Influence of electrolyte concentration on (a) exhaustion and fixation (b) K/S value, BSW and ASW

Influence of Alkali (Soda) Concentration

Alkali helps in the fixation of dyestuff with fiber by the formation of a covalent bond. The fixation rate was different under different alkali concentration. The exhaustion, fixation and K/S value of the samples dyed with Reactive Red 195 at different concentrations of alkali (2-20 g/l) are shown in Figure 5. The dyeing was carried out at the liquor ratio of 1:10 with 1 % o.w.f Reactive Red 195. The salt concentration used was 40 g/l, and the dye bath was run at 60℃ for 30 minutes. It can be observed from Figure 5 that the exhaustion, fixation and K/S values increased by increasing the amount of alkali indicating that the increasing amount of alkali content makes the dye bonded with fiber. From Figure 5 (a) it can be seen that exhaustion and fixation reached in the equilibrium state when the concentration of alkali was more than 40 g/l and the increasing rate of exhaustion, fixation and K/S was very high until the concentration was 40g/l. However 40 g/l alkali concentration was taken as the optimum alkali concentration for the subsequent dyeing process.

Influence of Liquor Ratio

Liquor ratio refers to the ratio of material to liquid. The importance of the liquor ratio is high in reactive dyeing. The less dye exhaustion, fixation and color strength of dyes may happen due to the higher or lower liquor ratio [19]. After achieving the optimum electrolyte and alkali concentration the experiments were carried out to study the influence of liquor ratio (1:05-1:30) on exhaustion, fixation and K/S value and to have the optimum liquor ratio. The dye bath was run with 1% o.w.f Reactive Red 195 containing electrolyte concentration 40 g/l and alkali concentration 10 g/l, dyeing time 30 minutes, dyeing temperature 60℃, and dye bath pH value 10.5. The effect of liquor ratio on exhaustion, fixation and color strength (K/S) is shown in Figure 6. For the liquor ratio 1:07 it was observed the highest exhaustion, fixation and color strength. And it is clear from Figure 6 that the exhaustion, fixation and color strength decreased with the increase of liquor ratio (more than 1:07) of the dye bath. Because in the higher liquor ratio the dye concentration becomes much lower and increases the possibility of dye hydrolysis. At liquor ratio 1:07, the highest exhaustion, fixation and K/S value were obtained as the maximum amount of dye molecules was exhausted and bonded with fiber. However, at much lower liquor 1:05, it was insufficient in quantity to dye the fabric. So, in this study, the optimum liquor ration was obtained 1:07 and used for the subsequent dyeing process.

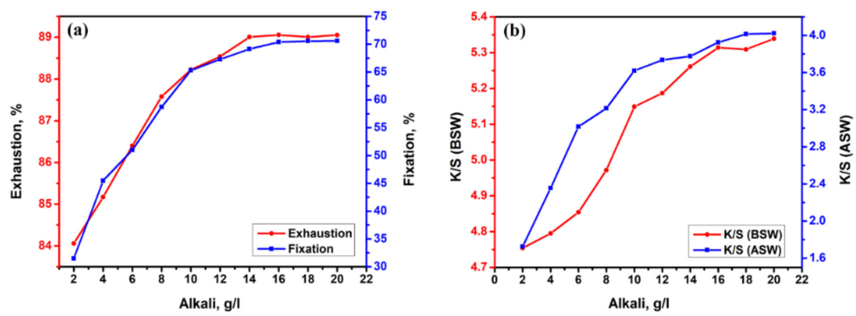

Figure 5: Influence of alkali concentration on (a) exhaustion and fixation (b) K/S value, BSW and ASW

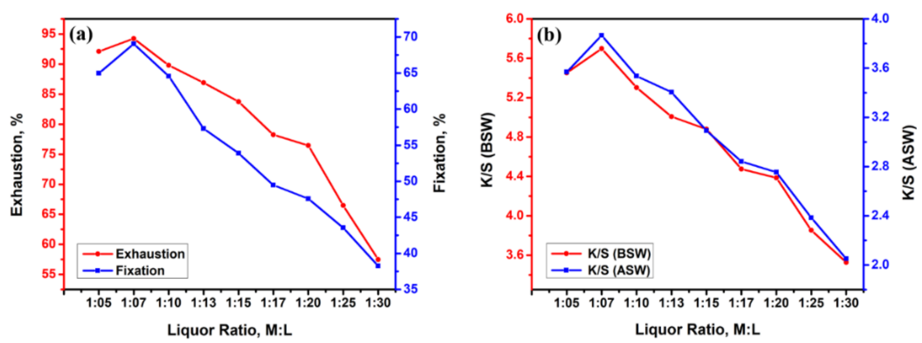

Figure 6: Influence of liquor ratio on (a) exhaustion and fixation (b) K/S value, BSW and ASW

Influence of Time

In order to observe the influence of dyeing time in reactive dyeing of cellulose fiber, the fabric was dyed under the condition of different dyeing times (1-100 min). Other dyeing factors were dyes 1% o.w.f, electrolyte 40 g/l, alkali 10 g/l, liquor ratio 1:07, dyeing temperature 60℃, and dye bath pH value 10.5. The influence of dyeing time on exhaustion, fixation and color strength is shown in Figure 7. It can be seen from Figure 7 that the exhaustion, fixation, and color strength (K/S) values increase over time. The dye bath reached the equilibrium state after 40 minutes and the exhaustion, fixation and color strength became slower. It was noticed because in 30 minutes the optimum amount of dyes has been exhausted and fixed so by increasing the dyeing time there was no much difference in exhaustion, fixation and K/S value. To achieve better results 30 minutes dyeing time was considered as suitable dyeing time for subsequent dyeing process of cellulose fiber with Reactive Red 195.

Influence of Temperature

The effects of different dyeing temperatures (30-90℃) on exhaustion, fixation and color strength (K/S) in reactive dyeing of cotton were observed. The recipe used in these experiments containing reactive dyes 1% o.w.f, electrolyte 40 g/l, alkali 10 g/l, liquor ratio 1:07, dyeing time 30 min, and dye bath pH value 10.5. It can be seen from Figure 8 that at a lower temperature (30℃), the dye exhaustion was 52%, but at this temperature, the dye fixation was very poor (18%). Similarly, at 30℃, K/S value (BSW) was 4.65, but at this temperature, the K/S value (ASW) was very low (1.12). The exhaustion, fixation and color strength (K/S) increased with the increase of temperature and the increasing rate was very high until the temperature was 60℃. There was no large difference found by using a higher temperature over 60℃, but by lowering the temperature less than 60℃, the exhaustion, fixation and K/S value were decreased. So, 60℃ temperature was selected as the optimum dyeing temperature for the next dyeing process.

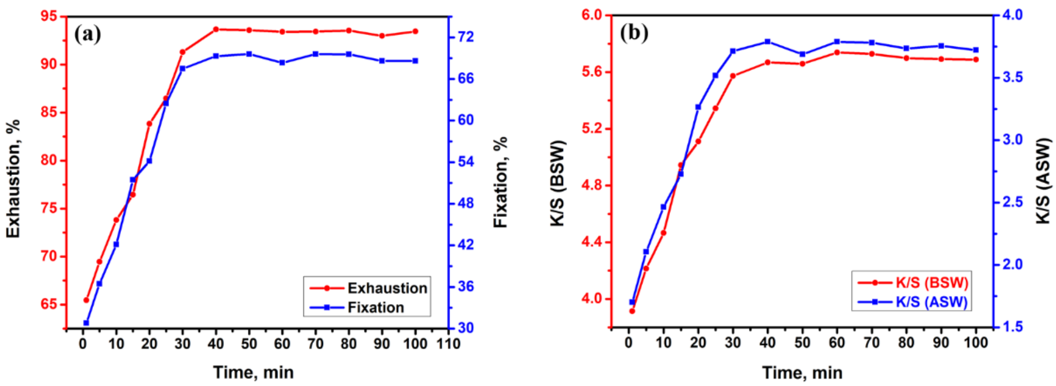

Figure 7: Influence of dyeing time on (a) exhaustion and fixation (b) K/S value, BSW and ASW

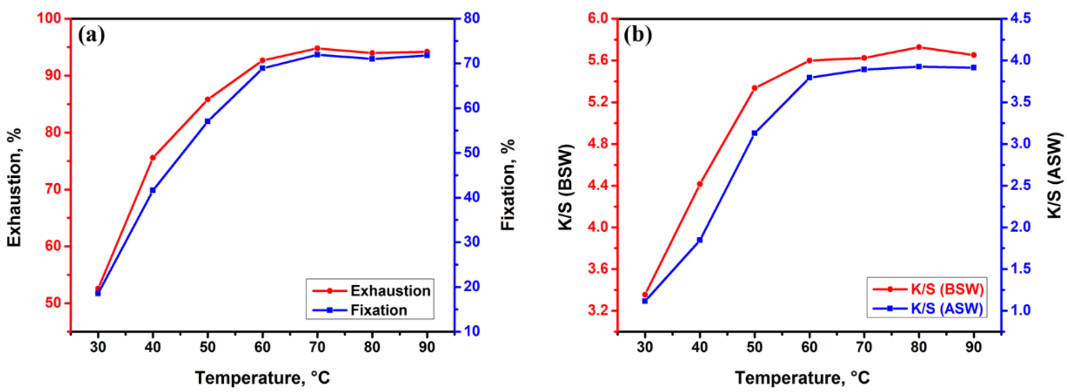

Figure 8: Influence of dyeing temperature on (a) exhaustion and fixation (b) K/S value, BSW and ASW

Influence of pH

In order to evaluate the influence of pH on exhaustion, fixation and color strength (K/S) and to get the optimum dye bath pH value for dyeing of cotton fabric with Reactive Red 195 different pH values (9-12) were used. While the other parameters remained unchanged. Such as the dyeing was carried out with dyes content 1% o.w.f, electrolyte concentration 40 g/l at a liquor ratio of 1:10. The dye bath was run for 30 minutes at a temperature of 60℃. The influence of pH on exhaustion, fixation and color strength is shown in Figure 9. From Figure 9, it can be seen that the exhaustion, fixation and color strength positively increases with the increasing of pH value but the difference was not much more due to using higher pH than 10.5. The lower exhaustion, fixation and K/S have been seen when the pH was lower than 10.5. So pH 10.5 was used as the optimum pH value for the dyeing of cellulose fiber with Reactive Red 195.

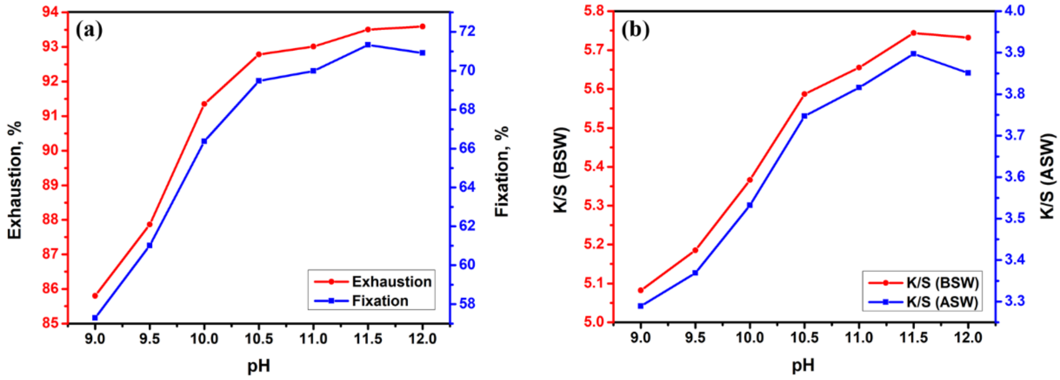

Figure 9: Influence of pH on (a) exhaustion and fixation (b) K/S value, BSW and ASW

Orthogonal Experiment (DoE)

The traditional experimental system is too difficult to use. The number of experiments will be increased by increasing the process parameters. To overcome this difficulty, the Taguchi method introduced a special orthogonal array design, and only limited experiments are needed to study the whole parameter space [6]. Four factors such as the concentration of electrolyte, concentration of alkali, dyeing time, and dyeing temperature were considered as the processing parameters for orthogonal analysis. Each factor was composed of three levels: low, medium, and high which are expressed by 1, 2 and, 3 respectively. According to the Taguchi method, if one process has four factors and each factor has three levels, orthogonal L9 array is applied to find out the optimum process parameters. By using Minitab® 17 statistical software (Minitab Inc, Coventry, UK) the Taguchi's experimental design (OA L9) was designed and analyzed. Table 1 shows the factors of dyeing and their levels measured in the experiment and the experimental layout is shown in Table 2. The level of parameters was selected through the pilot test (above single factor experiments). According to the groups of performance features the SNR of each response was calculated. Therefore, a larger SNR corresponds to better performance characteristics [20]. The greater the thinning coefficient and the dome height studied the superior performance. Once all SNR has been designed for each running experiment, Taguchi advocates using graphical methods to analyze the data.

Symbol	Dyeing Parameters	Levels		
		Level 1	Level 2	Level 3
A	Electrolyte (g/l)	30	40	50
B	Alkali (g/l)	08	10	12
C	Dyeing Time (min)	20	30	40
D	Dyeing Temp (℃)	50	60	70

Table 1: Dyeing Parameters (factors) and Levels for Orthogonal Analysis

Exp. No.	Factors				Responses	
	A	B	C	D	E, %	F, %
1	30	8	20	50	84.45	61.14
2	30	10	30	60	85.96	66.22
3	30	12	40	70	86.41	68.36
4	40	8	30	70	89.18	64.86
5	40	10	40	50	88.56	65.33
6	40	12	20	60	89.87	68.01
7	50	8	40	60	91.85	64.56
8	50	10	20	70	92.41	68.45
9	50	12	30	50	92.95	69.12

Table 2: Experimental Layout Using L9 Orthogonal Array and Results

Optimum Process Parameters

"The larger-the-better analysis" was designated for studying the impact of the factors according to the Taguchi's method [6]. The exhaustion and fixation were taken as two responses for Taguchi analysis. In order to determine the influence of process parameters on exhaustion, L9 OA was used in the experiment. Table 2 shows the experimental data and Table 3 shows the response table of the exhaustion SNR results. Delta statistics were defined as the highest average value of each factor minus the lowest average value, and the delta rank was assigned based on these values; the higher delta value represents rank 1, the second-highest represents rank 2, etc. This analysis helps to obtain more data about the process being investigated, and the largest delta value represents the largest contributor to exhaustion. The results show that the concentration of electrolyte has the greatest influence on the exhaustion, and the delta value of electrolyte concentration is 0.66. Alkali concentration is the second important factor, the delta value is 0.12, followed by dyeing temperature, and dyeing time having delta values of 0.07 and 0.05 respectively. Using the responses shown in Table 3, the main effect plot of the exhaustion was generated and shown in Figure 10. It can be seen from Figure 10, the third level of electrolyte concentration (A3), alkali concentration (B3), and dyeing temperature (D3) as well as the second level of dyeing time (C2) results in the maximum exhaustion value. The analysis of the signal-to-noise ratio also shows that the same level of variables (A3, B3, C2, and D3) are the best levels for the maximum exhaustion of the reactive dyes.

Level	A	B	C	D
1	38.65	38.93	38.97	38.95
2	39.01	38.98	39.02	39.01
3	39.31	39.06	38.98	39.02
Delta	0.66	0.12	0.05	0.07
Rank	1	2	4	3

Table 3: Response Table for S/N Ratios (Exhaustion, %)

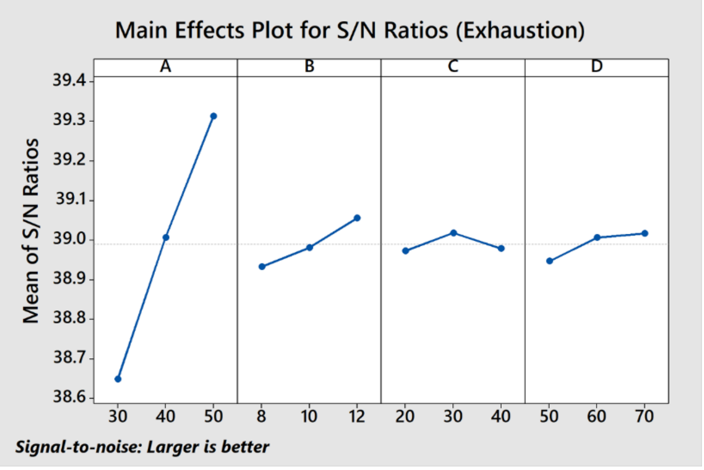

Figure 10: Main effect plots for S/N ratios (Exhaustion, %)

Further, to study the effect of the processing parameters on the fixation, L9 OA was used in this study. The experimental data of the fixation is shown in Table 2. "The larger-the-better analysis" was selected for studying the influence of the parameters on the fabric's fixation performance; a higher fixation is better. The response table for the S/N ratio analysis of the fixation of the dyed fabrics is shown in Table 4. The results indicate that the alkali concentration has the strongest effect on the fixation with a delta value of 0.66. The electrolyte concentration is the second most important factor with a delta value of 0.29, followed by the dyeing temperature, and dyeing time having delta values of 0.27, and 0.12 respectively. The graph of the main effects for the fixation was generated by using the responses given in Table 4 and shown in Figure 11. It can be seen from Figure 11 that the third level of electrolyte concentration (A3), alkali concentration (B3), and dyeing temperature (D3) as well as the second level of dyeing time (C2) provide the maximum value of the fixation. The S/N ratio results suggest the same levels of the variables (A3, B3, C2, and D3) as the optimum levels for the maximum fixation percentage in the dyeing of cellulose fiber with Reactive Red 195.

Level	A	B	C	D
1	36.28	36.06	36.36	36.27
2	36.40	36.48	36.48	36.42
3	36.57	36.71	36.40	36.55
Delta	0.29	0.66	0.12	0.27
Rank	2	1	4	3

Table 4: Response table for S/N Ratios (Fixation, %)

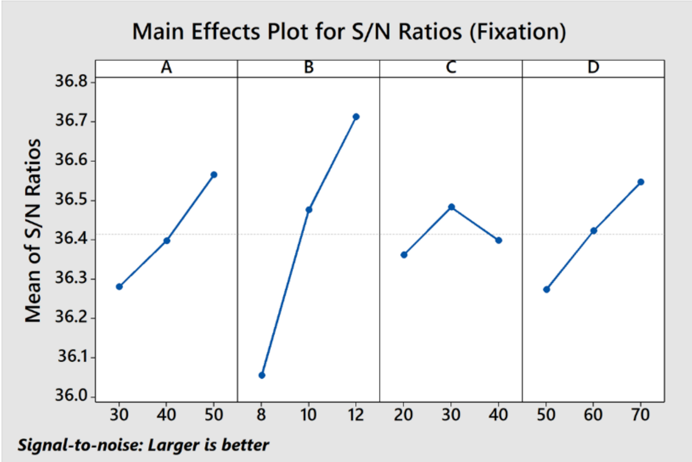

Figure 11: Main effect plots for S/N ratios (Fixation, %)

It was noticed that the optimum condition for dyeing of cellulose fiber with Reactive Red 195 for both responses i.e. exhaustion and fixation were A3, B3, C2, D3 to achieve the maximum exhaustion and fixation value. When the electrolyte concentration was 50 g/l, alkali concentration was 12 g/l, the dyeing time was 30 minutes, and the temperature was 70℃, the maximum exhaustion and fixation value for reactive dyeing was achieved. In order to confirm that the selected parameter had the highest exhaustion and fixation percentage, the experiment was run using optimum dyeing conditions from OA. Then the exhaustion and fixation value was confirmed showing 93.34% and 69.47% exhaustion and fixation respectively which were the highest exhaustion and fixation values among all the experiments of the Taguchi Orthogonal study.

Color Fastness Test

The samples were dyed using optimum dyeing conditions which were achieved from the Taguchi Orthogonal Array study. Then the dyed samples were tested against the color fastness to rubbing and color fastness to washing. The color staining and color change of the dyed samples were evaluated using a greyscale. The test results of the color fastness to rubbing and color fastness to washing are shown in Tables 5 and 6 respectively. It can be seen from Table 5 that the dry rubbing fastness is excellent and the wet rubbing fastness is also good for the samples dyed using optimum dyeing condition. The color fastness to washing of the samples dyed with Reactive Red 195 using optimum dyeing conditions is also excellent. (5 refers to the least amount of staining/ color change and 1 refers to the most amount of staining/ color change). So both rubbing and washing fastness properties are excellent for the dyed samples

Samples	Rubbing Fastness	
	Dry	Wet
1	4-5	3-4
2	5	4

Table 5: Color fastness to rubbing of the dyed samples (grade)

No.	Staining on						Color Change
	Wool	Acrylic	Polyester	Nylon	Cotton	Acetate	
1	5	4-5	5	5	4-5	5	4-5
2	5	4-5	5	5	4-5	5	4-5

Table 6: Color fastness to washing of the dyed samples (grade)

Conclusions

The influence of dyeing parameters on exhaustion, fixation and color strength (K/S) in the dyeing of cellulosic fiber with Reactive Red 195 was studied. Electrolyte, alkali, dyeing time, dyeing temperature and alkaline pH value had significant positive effects on exhaustion, fixation and color strength (K/S). The liquor ratio (1:07) had the highest positive result, and the higher liquor ratio showed a negative effect on exhaustion, fixation and color strength (K/S). The optimum dyeing condition for Reactive Red 195 was determined by using Orthogonal Array which was electrolyte concentration 50 g/l, alkali concentration 12 g/l, liquor ratio 1:07, dyeing time 30 minutes, temperature 70℃ and pH value 10.5. In a word, this research is helpful for us to understand the influence of process parameters on exhaustion, fixation, and color strength (K/S) in the dyeing of cellulose fiber with Reactive Red 195.

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Conflicts of Interest:

The authors declare no conflict of interest.

Abbreviations

Abs: Absorbance

ASW: After Soap Wash

BSW: Before Soap Wash

DOE: Design of Experiment

E: Exhaustion

F: Fixation

MCT: Monochlorotriazine

OA: Orthogonal Array

o.w.f: On Weight of Fabric

S/N: Signal to Noise

SNR: Signal to Noise Ratio

UV-Vis: Ultraviolet–Visible Spectroscopy

VS: Vinyl Sulphone

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