

A New Technique for Reactive Dye Uptake by Jute Fabrics and their Physico-mechanical Properties

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ABSTRACT

The mixture of Albafix WFF (Poly-diallyl-dimethyl ammonium chloride) sodium hydroxide was used as a modifier for surface modification of jute fabrics to improve the dyeabilities of jute fibers. Jute fabrics were dyed with reactive dye (Drimarene Red K8b) using conventional methods and some new approach of dyeing of jute fibers has been proposed. Reactive dye with or without sodium chloride and sodium carbonate were used to observe the nature of modification of jute fibers. Compared to the raw jute fibers, jute fibers dyed with reactive dye without using salt and sodium carbonate had higher color strength (K/S) values under the same dye concentration. Pretreated jute fabrics with the mixture of Albafix WFF and sodium hydroxide dyed with 1% Drimarene Red K8b only had 125% higher exhaustion, 25% higher fixation value than that obtained by normal dyeing, and exhibited good washing fastness as well.

Keywords: Jute fabric, dyeing, color strength, reactive dye

1. Introduction

Among the natural fibers, jute fiber occupies the second place in terms of world production levels of cellulosic fibers. One of the major countries of jute production is Bangladesh, due to its natural fertile soil. Jute fiber is a lignocellulosic fiber containing three main categories of chemical compounds, namely cellulose (58–63%), hemicellulose (20–24%), and lignin (12–15%), and some other small quantities of constituents such as fats, pectin, and aqueous extract. Owing to its eco-friendly and biodegradable nature, the

demand for jute fiber is raising day by day (Chattopadhyay et al., 2006; Samanta, et al., 2012). Nearly, 75% of jute goods are used as packaging materials, burlap, gunny cloth, (hessian), and sacks. Carpet Backing Cloth (CBC), the third major jute outlet, is another fast growing application of jute goods. Currently, it consists of roughly 15% of the world's jute goods consumption. The remaining products are carpet yarn, cordage, felts, padding, twine, ropes, decorative fabrics, and heavy duty miscellaneous items for industrial use. Jute carpet has been gaining popularity in recent years due to its

earthy look, interesting weaves and environmentally friendly composition. Jute is a fibrous plant grown and made into carpets primarily in India, Bangladesh and Pakistan. But till now jute carpet is facing some problems due to its color permanency, durability and odors.

Reactive dyes are anionic dyes which are mostly used to dye cellulosic fibers. These dyes contain a reactive group, either a haloheterocycle or an activated double bond, that, when applied to a fiber in an alkaline dye bath, forms a chemical bond with a hydroxyl group on the cellulosic fiber. Reactive dyeing is now the most important method for the coloration of cellulosic fibers. Since the cellulosic fibers assume a negative charge on their surface in aqueous solution, a larger amount of salt is usually required to reduce the electrostatic repulsion between fibers and anionic dyes. This is one source of pollutant in waste water produced from dye houses. Reactive dyes have a low utilization degree compared to other types of dyestuff, since the functional group also bonds to water, creating hydrolysis. When alkalinity is introduced in the dye bath in order to facilitate the formation of covalent bond between the fiber and the functional groups of the reactive dye, the only 60-65% dye utilization is attainable even with the use of salt in the normal dyeing systems (Subramanian et al., 2006). However, the hydrolysis of reactive dyes is usually accelerated by the increase in sodium hydroxide concentration. All these result in wastage of dyes and a highly colored dye effluent (Saowanee, et al., 2007; Periyasamy et al., 2011). Organic compounds containing industrial effluents from textile, dyeing and printing industries may cause skin cancer due to photosensitization and photodynamic damage (Hilal, 2011). Generally, there are two ways to overcome or alleviate these problems. One is to develop high substantivity, low salt, and high-fixation dyes (Periyasamy et al., 2011; Javad et al., 2005; Abo Farha, et al., 2010). The other one is to improve dyeability of fabrics via mechanical, chemical, and biological methods (Abo Farha et al., 2010; Ibrahim et al., 2005; Liu et al.

2008). However, most researches (Ali, et al., 2009; Song, 2007; Ristić & Ristić, 2012) focus on introducing cationic sites into the cellulosic fibers for interaction with anionic dyes. The fiber-reactive substituted amino compounds are the most common cationic modifiers. By introducing amino groups, the cellulosic fiber will be cationized giving a high substantivity for anionic dyes (Wang et al., 2010). In theory, dyeability of jute fiber is almost similar to cotton, which is generally dyed with direct dyes or reactive dyes, but the results are not very good due to its high crystallinity and high degree of orientation. (Liu et al., 2002). For this, many studies had been done to improve the dyeabilities of jute fiber, but most of them focused on the effect of pretreatments, namely scouring, bleaching and chemical compositions content on the dyeabilities of jute fiber. Although there is little effect on dye exhaustion and fixation, the environmental problems had not been alleviated because the dosage of salt and alkali during the dyeing process had not diminished. Wang et al., 2010 recently have shown that Glytac and sodium hydroxide treated jute fibers (scoured and bleached) dyed with reactive dyes in combination with sodium chloride and sodium carbonate had higher dyeability than those of untreated jute fibers.

The present paper focused on studying the different techniques in the dyeing of jute fabrics with reactive dyes. For this purpose, jute fabrics were treated with the mixture of Albafix WFF and sodium hydroxide in order to enhance dyeing ability of jute with reactive dye (Drimarene Red K-8b). The dyeing was performed with and without salt and sodium chloride. The aim of this work is to determine the effectiveness of the mixture of Albafix WFF and sodium hydroxide as a modifying agent of jute fabric in improving its dyeability with reactive dyes, and in achieving evenness of dye uptake without using salt and sodium chloride. It is also to determine the effectiveness of new techniques of dyeing of jute fabrics on the *K/S* value and fastness properties like wash fastness. Mechanical properties, tensile

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properties in particular, were evaluated and FTIR analysis was carried out to determine the effects of those techniques.

2. Experimental

2.1 Materials

2.1.1 Jute fabrics

Jute fabrics were used without further treatment (scoured and bleached). Plain woven structured fabrics of untreated jute yarn were collected from Bangladesh Jute Research Institute (BJRI). Specification of woven structured fabrics was – number of yarn per inch (both directions): 10-12, number of twist per inch: 4-5, yarn count: 241 tex, fabric strength: about 20MPa. Same yarns were used in both (warp and weft) direction of the fabrics.

2.1.2 Chemical

Albafix WFF (Poly-diallyl-dimethyl ammonium chloride (PDAC)) fixative from Huntsman, United States of America, Drimarene Red K-8b (reactive dye), Clariant, Switzerland and Ecal soap PA (nonionic detergent), Thailand were used in this research work. Sodium hydroxide (NaOH), sodium carbonate (Na₂CO₃), and sodium chloride (NaCl) from BDH, (UK) were also used in the present study.

2.2 Methods

2.2.1 Chemical treatment of jute fabrics

To observe the effect of chemical treatment, four different techniques as shown in Table 1 were followed to treat the jute fabrics. In all the cases, the concentration of different chemicals was- Albafix WFF: 10- 30 g/l, NaOH: 20g/l, NaCl: 40g/l, and Na₂CO₃: 10g/l. Also, 1% Drimarene Red K-8b was used in every case. All the treatments shown in Table 1 were carried out in a sealed steel container in a laboratory dyeing machine Rota Dyer with the material to liquor ratio of 1:15 and at the temperature of 60°C for 60 minutes. The samples were then taken out and washed with water at least three times in order to remove any residual chemical so that a final pH value of 7 was maintained and then dried in an open air. For wash fastness test, samples were washed by placing them in a mixture of Ecal soap PA (0.50gm/l) and water at the temperature of 95°C for 10 minutes. Afterwards samples were hot washed at 80°C for 10 minutes. Finally, samples were washed with normal water repeatedly until the pH value of 7 was obtained. One fabric was dyed with Drimarene Red K-8b using the procedure recommended by the dye manufacturer. This fabric sample was considered as a control sample (normal dyed sample).

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Table1. Different treatment procedures

AS-1	Treatment with Albafix WFF + NaOH
AS-2	Treatment with Albafix WFF + NaOH + Drimarene Red K8b
AS-3	Treatment of AS-1 sample with Drimarene Red K8b
AS-4	Treatment of AS-1 sample with Drimarene Red K8b + NaCl + Na ₂ CO ₃

2.3 Characterization for treated jute fabrics

2.3.1 Testing of exhaustion (%E)

The optical density of the dye solution before and after the dyeing was measured using Shimadzu UV- spectrophotometer (UV-1800, Shimadzu, Japan) at the maximum wavelength of absorbency (λ max). The dye bath exhaustion percentage (% E) was calculated using following equation.

$$E = \frac{(A_0 - A_1)}{(A_0)} \times 100\%. \quad (1)$$

where A_0 and A_1 are the absorbencies at maximum wavelength (λ max) of dye originally in the dye bath and of residual dye after dyeing, respectively.

2.3.2 Testing of color strength (K/S)

The reflectance values at all wavelengths were measured by using a Minolta Spectrophotometer. The reflectance (R) value of dyed fabrics at the maximum wavelength of absorbency (λ max) was found and color strength (K/S) was calculated using the built-in software of the computer color matching system. These values were calculated using the following Kubelka Munk equation.

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

where K was the Kubelka-Munk absorption coefficient and S is the scattering coefficient of the dyed sample at the wavelength of maximum absorption.

2.3.3 Determination of fixation (% F)

The percentage of dye fixation (% F) was calculated using the following equation:

$$F = \frac{(K/S)_a}{(K/S)_b} \times 100\%. \quad (3)$$

where $(K/S)_a$ and $(K/S)_b$ are the color strength with the values after soaping and before soaping (Sultana, & Zulhash, 2007), respectively.

2.3.4 Determination of total dye utilization (%T)

The total dye utilization percentage (% T) was calculated using the following equation.

$$T = \frac{E \times F}{100} \%. \quad (4)$$

2.3.5 Testing of wash fastness

ISO standards 105-C02 method was followed for wash fastness test. A specimen of 10 × 4 cm was attached with a multifiber fabric strip. Washing solution containing 5g/l soap was taken in the laboratory dyeing machine with a liquor ratio of 1:50. The specimen was treated for 45 minutes at 50 ± 2°C. The specimen was then removed and rinsed in normal water and dried in shadow. The change in color and degree of staining was evaluated visually using geometric grey scale.

2.3.6 FTIR spectroscopy

The surface chemistries of the treated and untreated jute fabrics were evaluated by using an FTIR Prestige – 21, Shimadzu, Japan Fourier Transform Infrared Spectroscopy (FTIR) instrument at a resolution of 2 cm⁻¹. Average of 30 scans was recorded in absorbance units from 4000 to 500 cm⁻¹.

2.3.7 Mechanical Test

The tensile properties of the fabrics were determined using a universal testing machine (model H50 KS-0404, Hounsfield Series S, UK). The load capacity was 1000 N; efficiency was within ± 1%. The crosshead speed was 5 mm/min and gage length was 60 mm.

3. Results and Discussion

As mentioned in a preceding section, four different treatments (AS-1 to AS-4) were considered to characterize the treated jute fabrics. The effects of treatment on different parameters are discussed in the sequel.

3.1 Effect of treatments on exhaustion (%E)

The effect of Albfix WFF in different procedures (AS-2 to AS-4) on the dyeability of jute fabrics with Drimarene Red K8b is observed at different concentrations (10-30 g/l). As shown in Fig. 1, the exhaustion of dyed fabrics increases significantly in every case. Exhaustion efficiency in every case is observed to be above 90% in this figure. The exhaustion of Drimarene Red K-8b in AS-3 procedure at 20g/l concentration is above 99% that leaves the dye bath colorless. This value is 125% more than that of normal

dyeing. The reason for this there is no chance for hydrolysis of dyes due to absence of salt and alkali in the dye bath. The results plotted in Fig. 1 shows that exhaustion value of the modified fiber was obviously higher than that of the unmodified fiber. This may be explained by the fact that the increase in zeta potential values of the jute fibers diminished the electrical repulsion between jute fibers and anionic dyes (Wang et al., 2010). On the other hand, by introducing quaternary groups, jute fiber would be cationized giving a high substantivity for anionic dyes because of Coulombic attraction between the positive charge on fiber and the negative charge on anionic dyes. Possible reaction mechanism among cellulose, amino compound and reactive dye can be explained by the scheme 1 to 4 below. Therefore, modification with the mixture of Albfix WFF and sodium hydroxide can increase the use percentage of reactive dye.

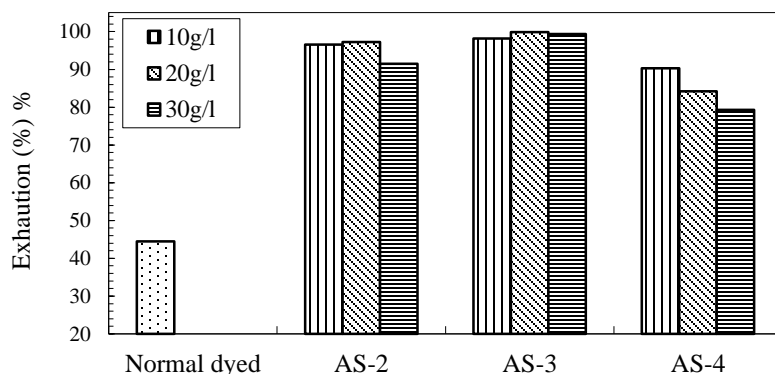
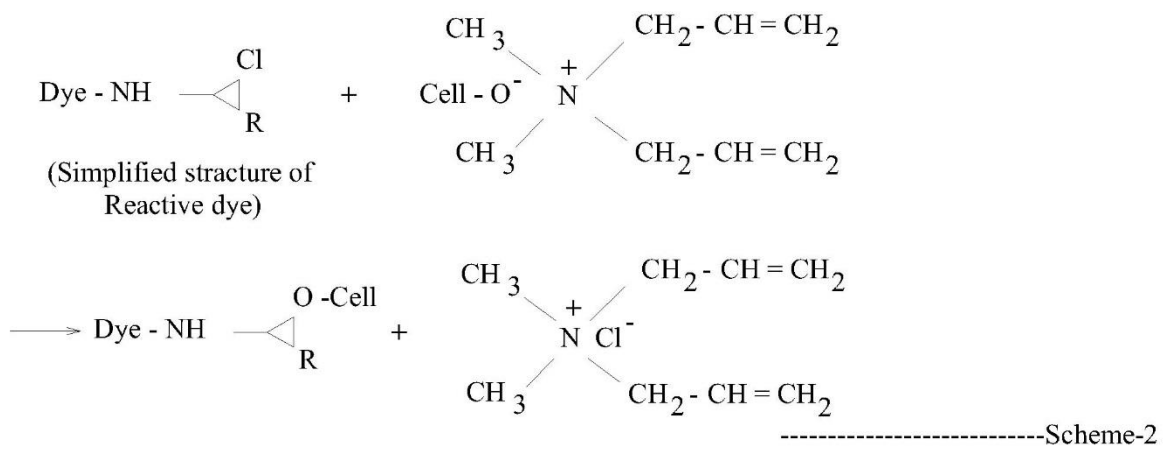
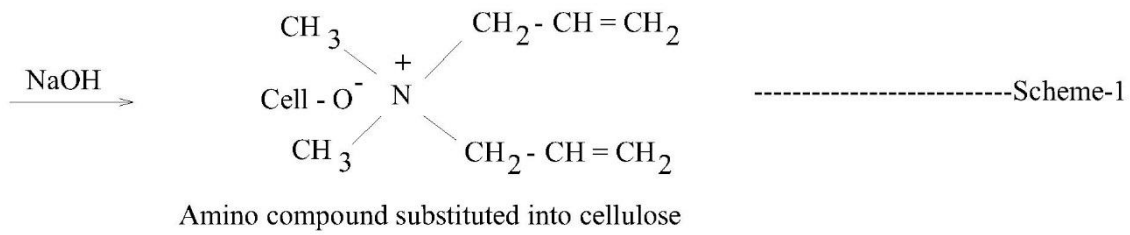
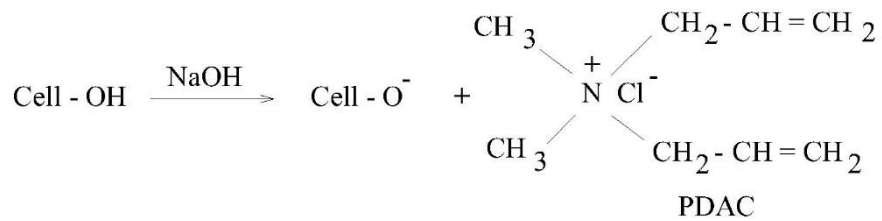
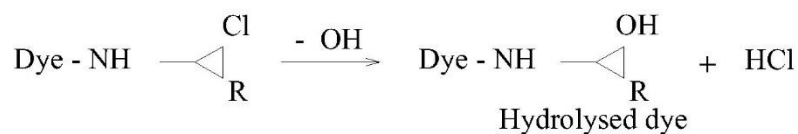
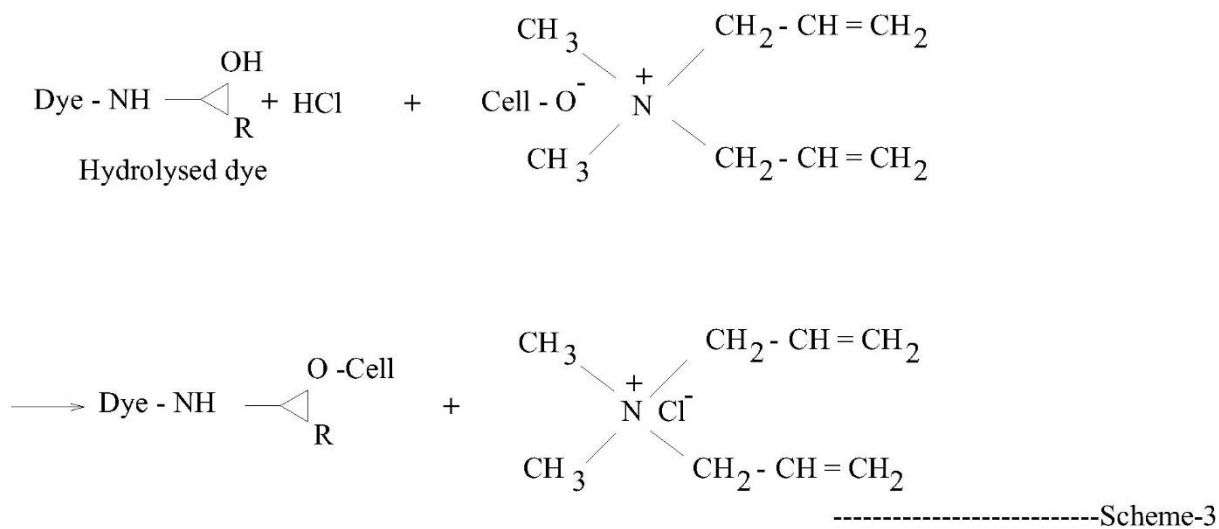


Figure 1. Exhaustion values for different dyed jute fabrics,

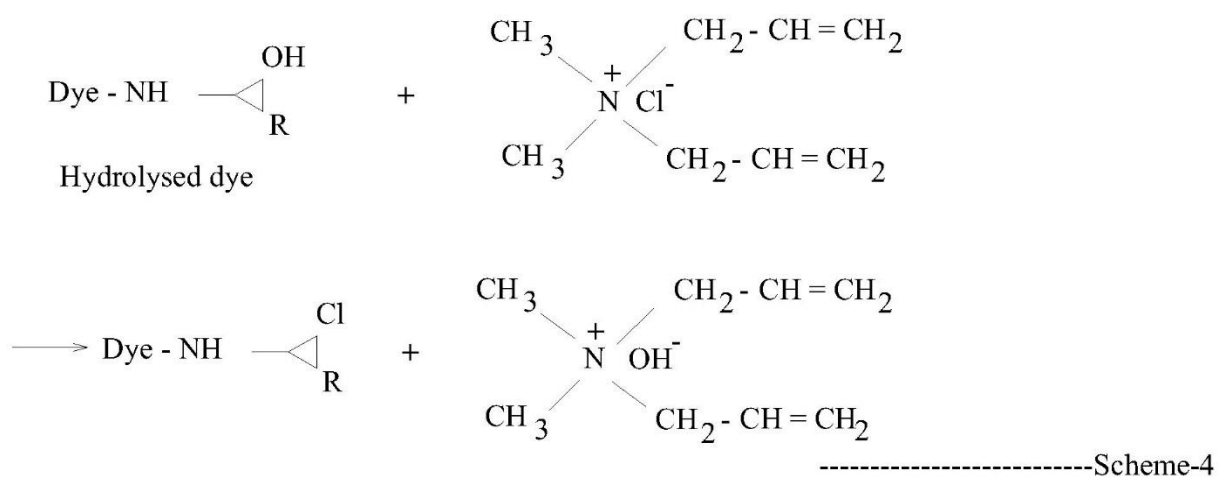




Side reaction of Reactive dye



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3.2 Effect of treatments on color strength (K/S)

The color depth of dyed jute fabrics was evaluated in terms of K/S values from the Kubelka- Munk function (Eq.2), where the reflectance R was measured with a Minolta

Spectrophotometer. Higher value of K/S indicates the higher dye uptake (depth of color) of the fabrics (Yamada et al., 2005). To evaluate the effect of depth of the color, the dyed jute fabrics are plotted against K/S values in Fig. 2.

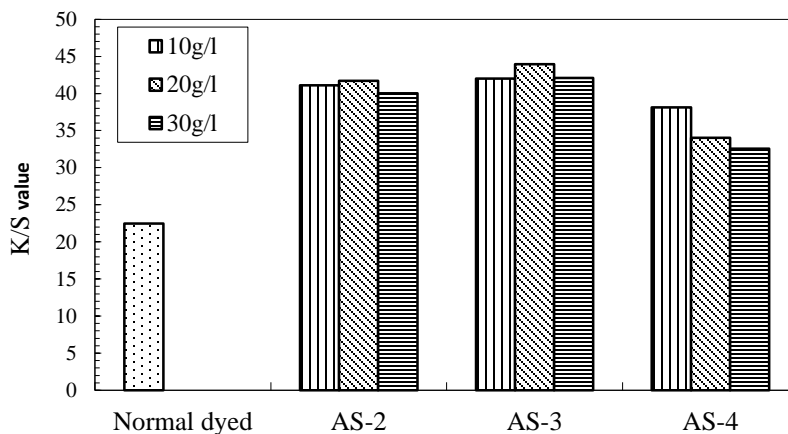


Figure 2. K/S value (before soap) for different dyed jute fabrics,

To observe the effect of the mixture of Albafix WFF and sodium hydroxide on dye uptake, jute fabrics were dyed with the 1% Drimarene Red K8b. From Fig.2, the following points are noted:

The K/S value of the normal dyed jute fabric is significantly lower than the K/S value of all the experimentally dyed jute fabrics. The K/S values are also presented in the Table 2. The maximum K/S value is found for the sample AS-3 (Albafix WFF + sodium hydroxide treated jute fabric dying with Drimarene Red K8b only) among all the samples. This value is 95% higher than the K/S value of normal dyed jute fabric. This demonstrates that without exhausting agent (sodium chloride) and fixing agent (sodium carbonate), AS-1 treated jute fiber molecule react with dye molecule significantly, so that dye uptake of the jute fiber is higher than that of normal dyed fiber (Scheme 2).

Apart from the sample AS-3, sample AS-2 gives the second highest K/S values among other dyed jute fabric, which is 85% higher than the K/S value of normal dyed jute fabric and only 5% lower K/S value than that of AS-3 treated fabric at 20g/l Albafix WFF concentration. It is also noted that jute fabrics treated simultaneously with the mixture of Albafix WFF, sodium hydroxide, and Drimarene Red K8b give lower K/S value than the K/S value of the treated fiber (AS-1) when dyed separately with Drimarene Red K8b only. This decrease in K/S value may be due to the presence of Albafix WFF, sodium hydroxide, and Drimarene Red K8b simultaneously in the dye bath hindering little bit the absorption of dye by the fiber. The above observations indicate that the treatment of jute fibers with the mixture of Albafix WFF and sodium hydroxide significantly increases the dye uptake than that of raw jute fibers. This is due to the fact that the dye reactivity on pretreated fabric

was greater because of the presence of amino groups provided by Albafix WFF (Yamada et al., 2005).

3.3 Effect of treatments on fixation properties

Table 2 describes that the fixation value of all the treated jute fabrics are higher than that of the untreated fabrics (normal dyed). This increased value is about 26.73% to 17.14% more than that of normal dyed jute fabrics. The sample AS-2 (treated with Albafix WFF, sodium hydroxide and Drimarene Red K8b) at the concentration of 20g/l gives highest fixation value among others. Fixation of the

experimentally dyed jute fibers was obviously higher than those of raw jute fibers under the same dyeing condition. This could be explained based on the forces of repulsion and attraction expected to occur during the dyeing process. These forces arise due to the presence of free hydroxyl groups in jute cellulose, anionic groups present in dyes, and amino ions in Albafix besides other factors (Gupta, & Haile, 2007). The presence of amino groups on treated jute fibers reduces the repulsion between the free hydroxyl groups of cellulose and the anionic groups of dyes. As a result, these treated jute fibers show higher fixation.

Table 2. Effect of concentration of Albafix WFF on dyeing performance

Treatment	Concentration (g/l)	K/S Before soap	K/S After soap	%E	%F	%T
Normal dyed	-	22.49	17.52	44.44	77.90	34.62
AS-2	10	41.10	39.90	96.58	97.08	93.76
	20	41.69	41.16	97.26	98.72	96.02
	30	40.01	38.60	92.50	96.48	89.24
AS-3	10	41.99	40.67	98.15	96.87	95.06
	20	43.94	42.66	99.88	97.09	96.97
	30	42.08	40.19	99.34	95.50	94.88
AS-4	10	38.12	36.72	90.32	96.33	87.00
	20	34.033	32.52	84.23	95.55	80.49
	30	32.56	29.71	79.30	91.25	72.36

3.4 Effect of treatment on total dye utilization (%T)

Table 2 shows that total dye utilization (%T) of all the treated samples is significantly higher than that of normal dyed fabric. Treated jute fabrics AS-3 corresponding to 20g/l Albafix WFF gives the highest %T value (96.97), which is 180% higher than that of the normal dyed jute fabric. On the other hand, treated jute fabrics AS-4 corresponding to 30g/l Albafix WFF gives the lowest %T value (72.36), which is 109% higher than that of the normal dyed jute fabrics. Hence, Albafix WFF and sodium hydroxide together increases the dyeability of jute fibers that can save approximately 62% dye.

3.5 Effect of treatment on wash fastness properties

The Table 3 shows the wash fastness rating for jute fabrics dyed in different ways as shown in Table 1 at the concentration of 20g/l Albafix WFF. It shows that there is not much difference between the normal dyed and the treated fabrics, confirming the effectiveness of dye fixation due to the mixture of Albafix WFF and sodium hydroxide. AS-4 treatment shows the best wash fastness rating among all the cases including normal dyed fabric. However, AS-2 and AS-3 treatments show good to moderate rating in both the cases of change in color and staining on cotton and acetate fiber and excellent to very good staining on other fibers. So it can be mentioned from Table 3 that these treatments

have no effect on change in color and staining in comparison with normal dyed jute fabric. It may be due to the formation of strong ionic bond between the fiber and dyes as it is equally good for the covalent bond that normally links the dye and fiber. The wash

fastness depends upon the physical and chemical properties of the fiber, the class of the dyes and their forces of interaction, and their interaction with soap solution.

Table 3. Wash fastness of untreated and treated jute fabrics

Procedure	Change in color	Change in staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Normal dyed	4	4-5	4	4-5	4-5	4-5	5
AS-2	3-4	4	3-4	4-5	5	4-5	5
AS-3	4	4	3-4	4-5	5	4-5	5
AS-4	4	4-5	4-5	4-5	5	5	5

Effect of concentration of Albafix WFF

As mention in the preceding section, three different concentrations (10 to 30 g/l) of Albafix WFF were used in this study. There is significant increase in *K/S* value and %*T* at every concentration of Albafix WFF in all cases compared to normal dyed fabrics. But it is noticeable that the effect of concentration of Albafix WFF contributes only very less amount and it can also be stated that these dyeing techniques largely increases the dyeing efficiency of reactive dye on jute fabrics. It is also necessary to mention that without following any pretreatment procedure these techniques are very much effective for jute dyeing. From Table 2, it is observed that the optimum concentration of Albafix WFF is 20g/l and best performance is found for the AS-3 treatment at this concentration, which gives the highest value of *K/S* (43.94), % *E* (99.88), %*F* (97.09) and %*T* (96.97).

3.7 FTIR analysis

Fig.3 shows the comparison of the FTIR spectrum of the raw jute, normal dyed, and treated (at 20g/l Albafix WFF concentration) jute fiber except AS-4 treatment. It can be

noted that there is an absorption band at 1730 cm^{-1} and 1240 cm^{-1} for the untreated jute fibers, which no longer exists for treated fibers. The hemicelluloses contain groups that absorb in the carbonyl region and ester group on surface of the fiber. They are soluble in aqueous alkaline solutions. During alkali treatment, a substantial portion of uronic acid and fatty substances might be removed resulting in disappearance of this peak at 1730 cm^{-1} and 1240 cm^{-1} (Liu, & Dai, 2007). In addition, the peak at 1622.16 cm^{-1} in the FT-IR absorption spectrum of the AS-1 treated jute fabric corresponded to the R-NH₂ bending for the primary amines. It was found that the Poly-diallyl-dimethylammonium chloride (PDAC) homopolymer were successfully applied on the jute fabric. The jute treated with PDAC showed 1503.54 cm^{-1} signals, which can be attributed to amide II (NH) modes on the basis of the structure of this chemical. This finding led us to the conclusion that presence of sodium hydroxide, PDAC homopolymer can be fixed into the jute fibers through the reaction of the aldehyde groups of the hemicellulose with the amino groups provided by PDAC, which react with reactive dye molecule largely so that its (AS-3) dye uptake increases significantly (scheme 3 and 4).

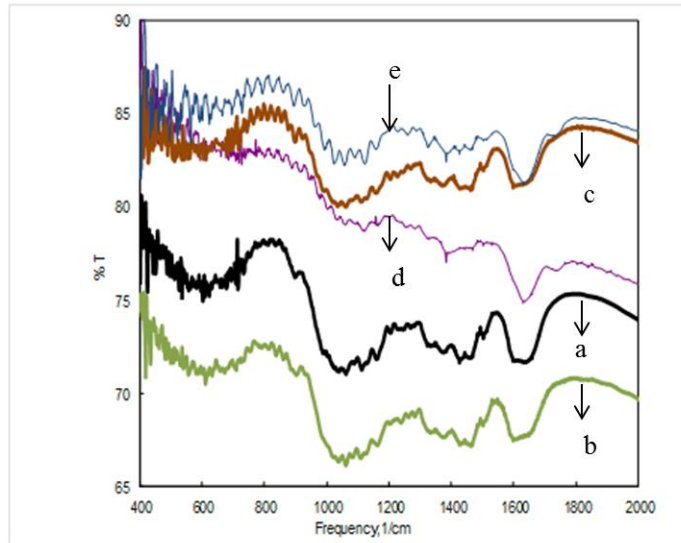


Figure 3. FTIR spectra of treated, (a) AS-1 (b) AS-2 (c) AS-3 (d) Untreated and, (e) normal dyed jute fabrics,

3.9 Effect of treatment on tensile strength

The tensile strengths of the raw and treated jute fabrics are shown in Fig. 4. It shows that apart from AS-3, all the treated fabrics including normal dyed jute have higher tensile strength than that of untreated jute fabrics. Specifically, the tensile strength of the AS-1, AS-2, AS-4 and normal dyed jute

J was increased by 50.78%, 42.80%, 25.64%, and 22.73%, respectively, compared with that of the untreated jute fabrics. However, it can be mentioned that the jute fabrics (AS-1) treated with the mixture of Albafix WFF and sodium hydroxide (without dye) has higher strength than that of the jute fabrics (AS-2) treated with Albafix WFF and sodium hydroxide in the presence of dye.

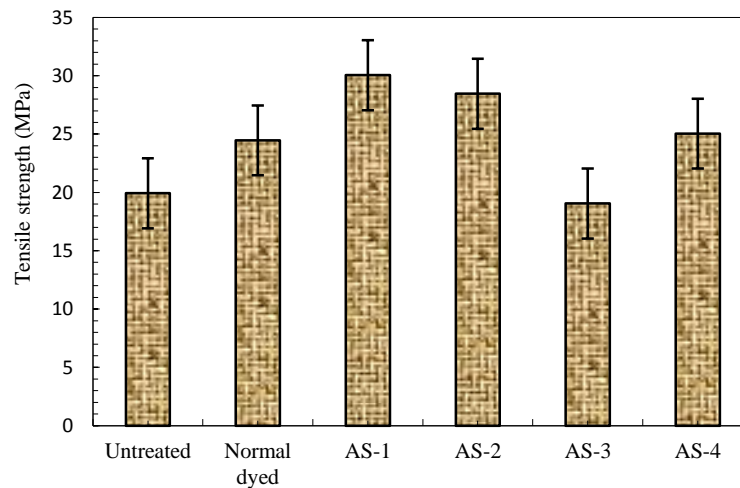


Figure 4. Tensile strength of treated, untreated and normal dyed jute fabrics,

4. Conclusion

The effect of different techniques of treatment of jute fibers on the dyeing performance was investigated and analyzed. Albafix WFF and sodium hydroxide treated jute fabric again treated with 1% Drimarene Red K8b had 125% higher exhaustion, and 25% higher fixation value than that obtained by normal dyeing, and also exhibited good wash fastness. There was no statistically significant change in the tensile strength of the fabric as a result of this treatment. By using this treatment procedure, the following advantages were observed: elimination of salt as an electrolyte, maximum fixation of dye, minimum hydrolysis of dye, significant savings in process costs, environmentally friendly.

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