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Disseminating the effect of water hardness on dyeing of cotton fabric with reactive dyes

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Abstract

Water, the most common and vital solvent for wet processes, such as dyeing, printing, rinsing, sizing, desizing, finishing, bleaching and many other purposes, has a great influence over textile processes. This project work was intended to investigate the parameters of various fastness properties at different quality of water hardness in the application of hot brand reactive dyes. influence of water quality on dyeing of cotton knit fabric with hot brand reactive dye. The effects of various fastness (color fastness to wash, pilling test, rubbing test and perspiration test) properties of dyes were also studied and reported in this study in details. Single color (Red) is used for the shade of 3% and varied water hardness of 13.5 PPM, 174 PPM, 114 PPM, 54 PPM and 246 PPM respectively. It is visualized that different grades of water hardness showed in different fastness and different depth of red hue for using reactive dyes having shade of 3%.

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Introduction

Water plays an important and dominating role in textile wet processing technology. Although several alternatives are getting into consideration, water is undoubtedly the most suitable as dyeing medium. So the quality of coloration is vastly dependent on quality of water Senthilnathan and Azeez (1999). Water quality contributes a significant part in determining the final shades of the products, consistency and production efficiency. One of the essential factors in influencing the dye house water quality is its hardness, which is defined as the presence of soluble calcium and magnesium salts in the water and expressed in the form of $CaCO_3$ equivalent. It is reported that the existence of hardness in water can cause dye precipitation and the precipitates can further promote dye aggregations, which result in color specks and loss of depth Sufian *et al.* (2016). So before dyeing these parameters should be in control.

Hardness, a physico-chemical property of water, is generally a measure of calcium and magnesium ions in water. Zinc, iron, strontium, aluminum, and manganese can also contribute to water hardness; however, they are generally present in very low concentrations Rahman *et al.* (2016). Initially, water hardness was understood to be a measure of the capacity of water to precipitate soap, which is in practice the sum of concentrations of all polyvalent cations present in water (Ca, Mg, Sr, Ba, Fe, Al, Mn, etc.) later it has been generally accepted that hardness is defined as the sum of the Ca and Mg concentrations, determined by the EDTA titrimetric method ,and expressed in mmol/l Uddin and Atiquzzaman (2014). The main sources of water for the textile industries in Bangladesh are collected from municipal water or deep tube well. Most of the textile wet processing industries is using Water Treatment Plant (WTP) to minimize the water hardness to an optimum level. They also use various chemicals depending on the types of wet processing employed (i.e. pre-treatment, dyeing, finishing, printing) to avoid the negative effects of remaining hardness of water. Even though the industries are facing lots of difficulties for water hardness, this is due to the poor performance of water softening plant, sequestering agent and inaccurate calculation of hardness in bath water. Maximum industries in Bangladesh consider only the hardness comes from water, but they do not consider the negative impacts of the chemicals and substrates that may contain the metal salts as impurities Khalil and Sarkar (2014).

Cotton is a natural cellulosic fiber. Cotton fibers are widely applied in textile industry due to its excellent properties of hygroscopicity, air permeability, biodegradability, no static electricity, etc. The dyeing of these fibers are generally done with reactive dyes due to its brilliancy, variety of hue, high wet fastness, convenient usage and high applicability. These reactive dyes contain a reactive group, either a halo heterocycle or an activated double bond, that, when applied to a fiber in an alkaline dye bath, forms a chemical bond with hydroxyl group on the cellulosic fiber Sindhe *et al.* (2015).

In 1955, Rattee and Stephen, working for ICI in England, developed a procedure for dyeing cotton with fiber-reactive dyes containing dichlorotriazine groups. Reactive dyes, particularly those used for dyeing cotton, have become one of the major classes of dye because of their good washing fastness, their bright shades and their versatile batch and continuous dyeing methods. The reactive groups of the various types of reactive dye have different chemical structures and show a wide range of reactivity. They were originally divided into cold- and hot-dyeing types. The most reactive types, such as DCT reactive dyes are applied at lower temperatures (20–40°C) and only require a weak alkali such as $NaHCO_3$ or Na_2CO_3 for fixation. The less reactive types, such as MCT dyes, need higher temperatures (80–90°C) and stronger alkalis such as Na_2CO_3 plus NaOH. Delituna (2010).

The objective of this study is to investigate the effects of different sources of water on cotton fabric dyeing using hot brand reactive dye. Five different sources of water with various hardness exhibits the change of red hue of reactive dye on cotton sample. To establish the result of exhaust dyeing on cotton using hot brand reactive dye, a number of fastness tests (wash, rubbing and perspiration) and spectrophotometric tests for determining color value has been performed in this work. A significant change has found in the dyed sample due to the effect hardness of water.

Materials and Methods

Substrate

Fabric Type: Single jersey

Fabric Construction:

Composition- 100% cotton

CPI- 48

WPI-38

TPI-14

Yarn count- 32 Ne

GSM-160

Color: Grey

Dyes, Chemicals & Auxiliaries

Dyes, Chemicals & Auxiliaries	Company
Reactive dye	Liyunsol Yellow 3RE (D&D)
Caustic soda (NaOH)	India
Hydrogen peroxide (H_2O_2)	India
Salt (NaCl)	China
Soda (Na_2CO_3)	China
Stabilizer	Japan
Sequestering agent	M/S Tex Trade Corporation
Wetting agent	United
Levelling agent	United

Equipment's

Name of Equipment	Manufacturer	Experiment Performed
Lab dyeing machine		Pretreatment& Dyeing
Spectrophotometer (Data color 650)	Data color, USA	Testing dyed sample
Dryer (Santex dryer)	China	Wet fabric dry
Electric balance	Ohaus Corporation, USA	Sample weighting
Micropipette	CAPP, Denmark	Measurement of solutions
Crockmeter	James Heal, England	Rubbing Test
Grey Scale	James Heal, England	Assessment of color fastness
Gyro wash	China	Assessment of colorfastness to washing
Light Fastness Tester	Starlet Korea	Assessment of colorfastness to light

Recipe of Pretreatment

Fabric weight : 10gm

Wetting agent : 2 gm/l

Sequestering agent : 2 gm/l

Stabilizer : 1 gm/l

H_2O_2 : 6 gm/ 1

Caustic soda : 4 gm/l

Temperature : 100˚C

Time : 1 hour

pH : 10-11

M: L : 1:10

Recipe of Dyeing

Fabric weight : 10 gm

Shade : 3%

Soda: : 20 gm/1

Salt: : 50 mg/1

Wetting agent : 2 cc/1

Leveling agent : 2 cc/1

Sequestering agent : 1.5 cc1

M: L : 1:10

pH : 10-11

Temperature : 70° C

Time : 1 hour

Source of Water

- Deep well water
- Pond water
- Sea water
- River water

Pretreatment Process

Single stage scouring and bleaching operation of the samples were done in the sample dyeing machine of Chemistry Laboratory, City University, Dhaka. The scouring and bleaching of 100% cotton knit fabric was performed with alkali (NaOH), hydrogen peroxide(H_2O_2) at 100˚C for one hour in discontinuous method.

Peroxide stabilizer was also used for H_2O_2stabilizing action. Then the sample was rinsed by cold water and dried in the air.

Dyeing Process (Exhaust Method)

First collect the pretreated fabric and calculate the chemicals and auxiliaries according to the recipe for the dyeing of the fabric. Then keep all the measured chemicals and auxiliaries in the dye pot and set it in the sample lab dyeing machine. The temperature was raised at 70°C by using 5˚C/min temperature gradient. Dyeing was carried out for 60 min. After dyeing the fabric, it was soaped with 1.5 gm/L soaping agent and washed again with cold water. Finally, the sample was washed again with hot water and it was dried. The dyeing curve of garments in three different grades of temperature along with process flow chart is as follows:

Grey Fabric inspection
↓
Pre-treatment (Scouring & Bleaching)
↓
Washing
↓
Drying
↓
Compare with standard swatch
↓
Trial dyeing of recipe
↓
Dispersion by autodoser
↓
Loading of (M/C)
↓
Tamp (40 up 70° run 60 Minute)
↓
Cooling (40°)
↓
Normal Wash
↓
Hot Wash (Detergent)
↓
Acid Wash
↓
Drying

Color Value & Color strength

A spectrophotometer is an instrument containing a monochromator, a device which produces a light beam containing wavelengths in a narrow band around a selected wavelength, and, a means of measuring the ratio of that beam's intensity as it enters and leaves a cuvette.

Fig. 1. Data color 650^{TM}.

Here datacolor650^{TM} of spectrophotometric series is used for successful color management of dyeing sample. The L* value is a measure of lightness and darkness of the color while the a* value indicates redness or greenness and b* value indicates yellowness and blueness. Reflectance value ® of all samples determined between the wavelength 400-700nm within 10 intervals using Data color 650^{TM}Spectrophotometer. Putting these values of R into the kubelka-munk theory to find out the color strength (K/S) of each specimen.

Color strength, $K/S = (1-R)^2 / 2R$

Where, R = reflectance at complete opacity, K= absorption coefficient, S= scattering coefficient.

Fastness Testing

Color fastness refers to the resistance of color to fade or bleed of a dyed or dyeing textile materials to various types of influences e.g. water, light, rubbing, washing, perspiration etc. to which they are normally exposed in textile manufacturing and in daily use. Four types of fastness namely color fastness to wash, color fastness to rubbing, color fastness to water, color fastness to perspiration were performed on the on the sample.

Color Fastness to Wash (ISO 105 C06 A2S-2010)

Apparatus, materials and reagent

- Rota wash machine
- Non-corrodible steel balls
- Multi fiber DW
- ECE Detergent
- Sodium Perborate Tetrahydrate ($NaBO_3.4H_2O$)
- Grade 3 Water
- Grey scale for assessing change in color (ISO 105-AO2)
- Grey scale for assessing staining (ISO 150-AO3)
- Measuring Cylinder
- Sewing machine
- Light box

Procedure

- First solution was prepared by dissolving 4g ECE detergent and Ig Sodium Perborate Tetrahydrade.
- Then sample and multi fiber were cut into 100x40mm and sewing them along one of the shorter edges.
- Then temperature was set at 40°C in the rota wash m/c for option A2S.
- 150ml wash liquor sol" were poured into the steel container by using measuring cylinder.
- 10 steel balls were used into the container
- Then the sample with multi fiber were kept into the container.
- Finally the containers with sample were set in the Rota wash m/c for 30 minutes at 40°C
- After completing the test, then the samples were unloaded and rinsed twice for each sample with normal water.
- Then the specimens, the changes of shade and degree of staining is measured by grey scale for assessing change in color and grey scale for assessing staining in color.
- The evaluations were done in the light box with D65 light.

Fig. 2. SDC Multi fiber Fabric.

Color Fastness to Rubbing (ISO 105 X12:2016)

Apparatus and Materials

- Crock meter
- Rubbing cloth
- Distilled water
- Sock paper
- Balance
- Specimen
- Grey scale for assessing color change & staining
- Light Box

Procedure

- Fist sample was set in the crock meter then dry rubbing cloth was mounted with rubbing finger by ring and dry rubbing test was done by 10 cycle of rubbing finger with in to and fro movement.
- For wet rubbing test, the rubbing cloth was wetted by distilled water and the wet take up percentage must be 95% to 100%. Forgetting this take up percentage of water was needed. For removing extra water blotting paper was needed.
- To get the right wet take up percentage balance is needed to make eight the dry weight of the cloth and the wet weight of the cloth.
- After getting the right take percentage, the wetted cloth was mounted in the rubbing finger.
- Then the wet rubbing test was completed by 10 cycle of rubbing finger with cloth in to and fro movement.
- Then the tested rubbing cloth was kept in the condition rack for air dry.
- After drying the cloth, it was evaluated by grey scale for assessing staining also keeping three layers of white rubbing cloth under tested cloth.
- The evaluation was done in the light box with D65 light.

Fig. 3. Crock Meter.

Color Fastness to Perspiration (ISO 105 E04:2013)

Color fastness to perspiration is the degree of color keeping of textile in sweat or perspiration.

Apparatus, Materials and Reagent

- Perspirometer
- Balance with weighing accuracy of +/- 0.001g

Drying oven

- pH meter
- Volumetric flask
- Petridish
- Multi fiber test fabric and grey scale for staining and color change

Procedure

➢ The sample has to be tested in the delivered condition; don't wash and/or tumble it before testing

➢ It has to be used only multi fiber from James Heal, type DW the face side of the fabric/ sample has to be tested one liter of the perspiration solution has to be prepared freshly the solution for the alkaline perspiration test has to be prepared with the salt Na_2 HPO_4 $12H_2O$ salt disodium hydrogen orthophate dodecahydrate the uniform penetration of the specimen has to be ensured by using liquor with a liquor ration 50:1 for 30 min.

➢ The penetration of both parts (fabric and multi fiber) has to be done in a flat bottomed petri dish (A). After this process the specimen weight has to be 2x to 2,5x of the original weight The test equipment has to be heated up to 37°C at least 1 hour before testing even you test only one , two or three specimens you have to use at least 5 glass or acrylic resin plates (F) (place them first) to ensure that the pressure (loadin) will work on the specimen correctly; the screws should be fixed perfectly to guarantee a permanent defined pressure it has to be ensured that the plates are even/ flat.

Fig. 4. Perspiration Test Machine.

Results and discussion

Visual Assessment (Rain, Pond, River, Deep well & Sea water)

The visual assessment of reactive dyed sample in exhaust method using five different sources of water namely rain water, pond water, river water, deep well water and sea water is tabulated in Table 1. There is different depth of red shade of hot brand reactive dye on 100% cotton knit fabric has been obtained. From visual assessment it has been found that among five samples the brighter dark red shade of reactive dye was achieved for rain water. Deep well water also gives brighter red shade but other three sample provides a lighter shade of reactive dye.

Table 1. Illustrated View of all Dyed Samples.

Water Source	Color	Reactive Dye (Hot brand)	Sample	Pictorial View
Rain water	Red	Hot brand	S_1	
Pond water	Red	Hot brand	S_2	
River water	Red	Hot brand	S_3	
Deep well water	Red	Hot brand	S_4	
Sea water	Red	Hot brand	S_5	

Grading of Water According to Hardness Test Result

Table 2 represents the hardness test results. It has been observed from the following hardness test result that only rain water gives the value of soft water. Very hard water value was obtained for sea water and the result is 246 PPM. Deep tap water falls in the category of slightly hard water whereas river water was in the moderately hard region.

Rain water is found to be softer because naturally rain water contain low concentration of multivalent cations e.g. calcium and magnesium. On the other hand, sea water is a complex mixture of both mon and multivalent ions that are responsible for its highest hardness characteristics (Weingärtner 2006)

Table 2. Classification of Water According to Hardness Test Result.

Water Source	Test Result of Hardness	Classification of Water
Rain water (S_1)	13.5 PPM	Soft water
Pond water (S_2)	174 PPM	Hard water
River water (S_3)	114PPM	Moderately hard water
Deep tap water (S_4)	54 PPM	Slightly hard water
Sea water (S_5)	246 PPM	Very hard water

CIE Color Coordinates

Table 3 indicates the CIE color coordinates of dyed samples. L* values of the sample relates to brightness/lightness. The a* value indicates redness or greenness and b* value indicates yellowness and blueness. It has been found that sample S_5 and S_3provides darker and bright red color with sea and river water. Although the rest three sample shows better depth of red hue along with sample 3 & 4. The most brighter red shade was achieved from sample S_3. While the most darker red shade obtained from sample 5. These variations may be occurred due to different ion composition in different samples.

Table 3. CIE Color Coordinates of Dyed Sample (Rain, Pond, River, Deep well and River water).

Sample	Color Coordinates					
	Illu/Obs	L*	a*	b*	c*	h°
S1	D_{65-10}	42.79	57.17	14.19	58.90	13.94
	A-10	47.07	53.16	20.71	57.05	21.29
S2	D_{65-10}	42.91	57.25	14.58	59.07	14.29
	A-10	47.25	53.30	21.30	57.40	21.78
S3	D_{65-10}	42.58	57.72	14.71	59.57	14.29
	A-10	47.00	53.54	21.63	57.74	22.00
S4	D_{65-10}	42.69	46.47	13.96	58.17	13.89
	A-10	46.94	52.64	20.61	56.53	21.38
S5	D_{65-10}	40.72	57.18	14.76	59.05	14.47
	A-10	44.94	52.78	12.25	56.89	21.93

Test Result of Color Fastness to Wash (ISO 105 C06 Az5 -2010)

In the color fastness to wash test (Fig. 5), it has been found that color change and color staining rating of S_2& S_5sample was found good towards excellent remarks than other samples. Color staining result of all samples defines good wash fastness rating. But sample S_1, $S_3$and sample S_4provides fair to good fastness against change in color. It has been observed that hard water and very hard water treated dyed sample gives a nearest excellent result of wash fastness. This type of results obtained due to various mineral compositions of the water samples. Rahman *et al.* (2016).

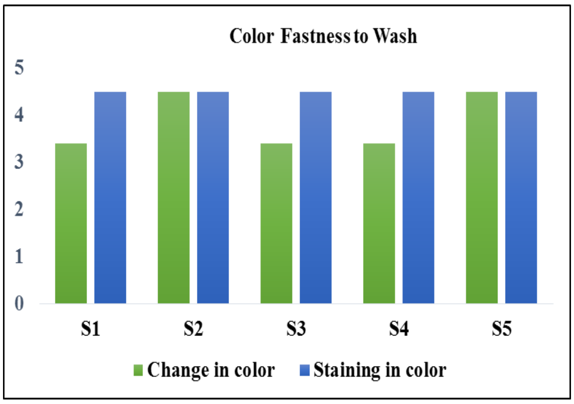

Fig. 5. Rating of Color Fastness to Wash of All Samples.

Test Result of Color Fastness to Rubbing (ISO 105 X12:2016)

It was a noticeable matter that after reactive dyeing of cotton fabric individually by using five different source of water, dry rubbing fastness gave good towards excellent result of rubbing fastness for sample S_1, S_3, S_4 and S_5. And the best wet rubbing exhibits good result for sample S_4 and sample S_5 (Fig. 6). From the analysis of rubbing fastness result sample S_4 and S_5 provides better rubbing performance rating among all the dyed samples. This result indicates that water hardness has significant influence on rubbing test result Rahman *et al.* (2016).

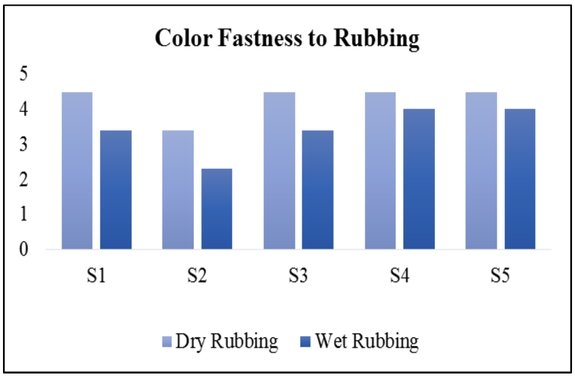

Fig. 6. Rating of Color Fastness to Rubbing of All Samples.

Test Result of Color Fastness to Perspiration (both acidic & alkaline solution)

In color fastness to perspiration test, a good fastness rating against acid and alkaline perspiration was obtained for S_3, S_4 and S_5 sample (Fig. 7). Here sample $S_1$and S_2has shown a fair to good rating of acidic and alkaline perspiration fastness. This is due to the presence of higher amount of metallic ions in water samples that may interact with dye materials. Shinde *et al.* (2015).

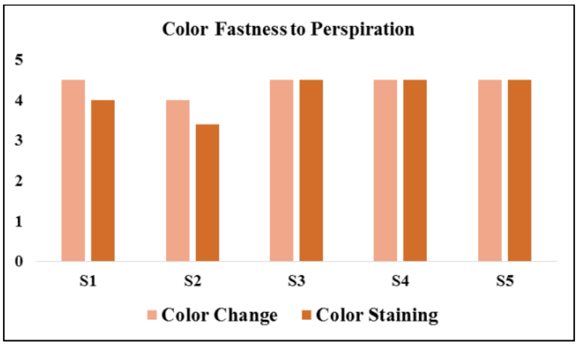

Fig. 7. Rating of Color Fastness to Perspiration of All Samples.

Test Result of Pilling Resistance (ISO 105 E04: 2013)

A comparison of pilling rating of fabric dyed with hot brand reactive dye using five different sources of water is given in Fig. 8. As it can be noticed, the best result was found for red color with sample S_1, S_2 and S_5. There is slight decrease in pilling rating with river and deep well water used sample of S_3 and S_4. This result may be occurred due to presence of ions activities in different concentrations. Shinde *et al.* (2015).

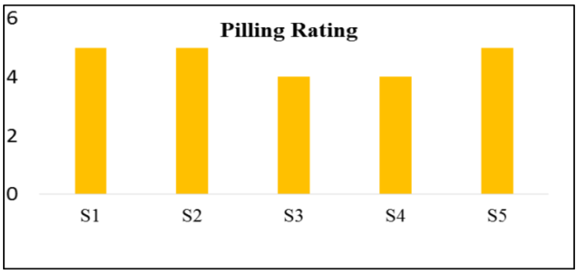

Fig. 8. Rating of Pilling Resistance of All Samples.

Conclusion

This project work is carried out to assess the properties of samples dyed with hot brand reactive dyes using different sources of water. Rain water, pond water, river water, deep well water and sea water was taken for this study. Hardness of water was examined in hardness kit method. Pretreated cotton samples were dyed with hot brand reactive dye in exhaust dyeing method with these different sources of water. To evaluate the dyeing properties a number of fastness tests were done such as color fastness to washing, color fastness to rubbing, color fastness to perspiration. Pilling test was also done as a physical test in this work. For testing color coordinates of reactive red hue spectrophotometer was used. Sample S_5 and S_3provides darker and bright red color with sea and river water. The most brighter red shade was achieved from sample S_3but the water was moderately hard. Sea water dyed sample (S_5) provides good to excellent fastness (wash, rubbing & perspiration) properties among all samples. Whereas sea water was found as very hard water. But soft water treated sample also gives good fastness result and rest three sample gives fair to good fastness rating. Test result of pilling shows that sample S_1, S_2 and $S_5$was found better resistance than other two sample. From the above discussions it can be concluded that the hard water treated sample provides better result than soft water. Due to presence of high metallic compound in sea water the exhaustion of dye will be more but hard water causes various problem in wet processing. To avoid the harmful effects of hard water on textile it will be desired or preferred to use soft water considering all performance with dyeing and fastness properties.

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