Study on Waterless Chemical Effect on Indigo Rope Dyeing

Ejajul Hoque[1], G.M. Faysal

Abstract- Water is life. A pair of jeans is a result of processes that need thousands of liter of water. Various chemicals have been manufactured for indigo and sulfur dyeing under the concept of 'zero water denim' or 'waterless dyeing'. However, dyers are not adopting the new technique for many reasons, including price, shade and colorfastness issues. In this paper, the author experimented with a waterless indigo/sulfur dyeing chemical (Premaclean WF-I) to dye a batch of cotton yarn in rope form with indigo dye. After dyeing, colorfastness is examined and dyeing cost is estimated. The result shows that denim mills can save about 60% freshwater in indigo rope dyeing step only for a 7.5% negotiation in FOB per pair of jeans. So, this study shall be a guide for dyers who are confused about the adoption of eco-friendly dyeing of denim warp yarn.

Index Terms- Jeans, Denim Fabric, Rope Dyeing, Indigo Dyeing, Waterless Dyeing, Eco-friendly Dyeing, Sustainability

1 Introduction

1.1 Prospect of RMG Industry in Bangladesh

The ready-made garment (RMG) is the most prospective sector for Bangladesh. The sector has been the second-largest RMG exporters on the earth just after China since 2009[1]. Bangladeshi products are serving well to the customers in the exporting countries and thus customers are getting more inclined towards the "Made in Bangladesh" tag. Now the count of RMG units is more than 3,000 and export earnings have reached USD 32 billion with more than one hundred countries and around 150 international apparel brands using 'made in Bangladesh' knit garments and woven products[2]. In 2018-19 FY, Bangladesh exported USD 34.13 Billion worth RMG products to the USA, EU and rest of the world, which was 84.21% of the total export value of Bangladesh (Data Source: EPB). Bangladeshi RMG sector has seen 11.49% growth in 2018-2019 FY from 2017-18 FY (Data Source: EPB).

1.2 Prospect of Denim Industry in Bangladesh

Denim is a unisex fashionable woven wear for all ages. The global jeans business is increasing in a drastic way because of its comfort-ability, trend, and performance. The global jeans sell was calculated at approximately USD 66.02 billion in 2018 and is anticipated to go approximately USD 85.4 billion by 2025, at a CAGR of around 3.7% between 2019 and 2025[3]. Bangladesh alone has exported denim products of total worth USD 2.22 billion to the EU and USA in 2018-2019 FY (Data source: Eurostat and Otexa, compiled by TextileToday). In fact, Bangladesh is the principal exporter of denim garments in the European market and third-largest exporter in the USA. So, keeping a huge market of denim jeans in the forecast, Bangladesh has lots of opportunities and potential to acquire a good order form big customers.

1.3 Denim Manufacturing in Brief

Denim is a cotton warp-prominent twill fabric where the weft passes below two or more warp threads[4]. Common steps of denim fabric production are warping, dyeing, sizing, weaving, finishing, and inspection. Unlike other woven fabrics, denim warp yarns are dyed after warping. Initially, all denim utilized ring-spun (RS) yarns, but in the 70s, ring yarns were replaced for denim due to the lesser price and rapid manufacturing of open-end (OE) yarn, known as rotor spinning[5]. Yarns used for warp of denim fabrics are typically 100% Cotton in composition and comparatively thicker than other woven fabrics. Warping can be two types depending on dyeing machine or process – Ball warping and Beam warping. Then it is dyed, with Indigo or Sulfur dyes, whether in sheet form or in rope form. Then sizing is done followed by weaving and finishing.

1.4 Textile Dyeing

Dyeing is textile wet processing in which color is incorporated into fibrous products in different forms such as loose fiber, yarn, fabric, and nonwoven in a suitable dyeing machine[6]. Coloring matters are two types – dyes and pigments. According to the method of use, dyes may be classified into seven types – Direct, Acid, Basic, Reactive, Vat, Disperse and Azoic dyes. Pigments are insoluble coloring matters, generally attached to the fabric with the help of a binder in the printing process. A dyed or printed textile material is expected to exhibit proper color fastness during its using period. In Bangladesh, textile industries are doing fiber dyeing, yarn dyeing, and solid fabric dyeing. Generally, non-denim cotton woven goods are dyed with reactive dyes here for its good colorfastness.

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1.5 Vat Dye Principles

Vat dyes, so-called because Indigo - the first member to be affiliated to this king of colors were dyed on textile materials in wooden pots or vats in the early days, are water-insoluble colored compounds[7]. To make this dye soluble, two steps of reaction is required. First, reduction of vat dye into leuco vat dye by sodium hydrosulphide. Second, neutralization of leuco vat dye with caustic soda to give soluble sodium salt of leuco vat dye. After dyeing, oxidation is needed to reconvert the water-soluble sodium salt of leuco vat dye into the water-insoluble original vat dye. Rinsing at ambient temperatures in 2/3 rinsing baths after oxidation is normally adequate to remove alkali and unoxidized leuco compounds [5].

1.6 Environmental Hazard in Traditional Dyeing

In traditional rope, dyeing is a water-consuming process because it technically needs lots of flow of water in wash boxes. Pre-wash boxes remove caustic soda and other auxiliaries completely from the substrate by a thorough rinse. Continuous rinsing accelerates temperature fall and prepares the substrate for indigo dyeing at room temperature. Post-wash boxes require a constant flow of water for proper elimination of unfix dyes and chemicals from dyed yarn surface. About 75 L/min water flow is required in wash boxes, so, a total of 450 L/min water flow is required in all wash boxes (6) while dyeing. As per the Greenpeace report for producing two billion jeans pants every year, it takes a total of 1.7 million tons of chemicals and water consumption can reach as much as 7,000 liters per one pair[8]. Consumption of large quantities of chemicals and freshwater ends up in increased product cost and larger volume of chemically loaded effluents; particularly excess sodium dithionite, unfixed indigo dye and their byproducts[9].

1.7 Present Scenario of Water Conservation in the Denim Industry

As denim manufacturing is one of the world's most water-intensive processes, the efforts to reduce its environmental impact were significant over the last fifteen years[10]. There are many ideas offered to manufacturers of jeans today; organic denim, less polluting indigo dyeing and washing, zero water techniques, oxygen, and ozone washing, reusing processes, sustainable projects, and so on[11]. Most of the past studies are involved with denim finishing technologies that are carried out in garments form however they are in no practical use at all. Ozone fading and Laser fading instead of bleaching or pumic stone wash are the notable waterless finishing technologies. It (Ozone) fades clothing and provides huge savings in water and chemicals unlike the typical processes of fading based on stone, bleaching powder and enzymes that cause a loss of tearing and tensile strength in thicker zones as well as there can be seen stone spots[12]. Laser technologies are comparatively faster and easier to control as well as simple, accurate and almost waterless[13]. Water-saving and recycling attempts are likely to create huge outcomes by the reduced cost of purchased water and lessened cost of the effluent treatment plant, as a result, making the money accessible for further extension of the plant or up-gradation of procedure and machine to facilitate better quality[14]. Also, many zero water enzymes, bleaching, and softening chemicals are manufactured by various chemical manufacturers which are almost not in use for their impractical price.

2 Materials and Method

2.1 Materials

320 ends of 6s Ne 100% cotton ring-spun yarn is drawn from creel to accumulate as continuous strands or rope. A set of a total of 24 ropes is dyed together in the Smartec rope dyeing machine of China. The set length was 2000 meter and the calculated weight of the material is 1530 kg.

2.2 Chemicals

In this study Prosind WP (Surface active agent) and Premaclean WF-I (polymeric dye-fixing agent) chemicals of Proser Chemicals, Adana, Turkey are used. Besides, pure indigo dye, caustic soda, hydrose, wetting agent, sequestering agent, acetic acid are used.

2.3 Method

2.3.1 Traditional Way of Dyeing

In Bangladeshi denim industries, there are mainly two kinds of continuous denim warp yarn dyeing machines – slasher and rope. When yarns are incoming into the dyeing vat in the sheet form it is called slasher or sheet dyeing. On the contrary, the machine where the yarn is fed into the dye box in rope form is known as rope dyeing. In this study, rope dyeing machine is used. Rope of 300 to 400 yarns is continuously colored in the below stages: 1. Pre-treatment, 2. Prewashing, 3. Indigo dip, and 4. Post washing[9]. At first, materials are fed into a pre-treatment bath to treat with Caustic Soda, Wetting Agent and Sequestering agent at 70-80 °C.

Pre-Wetting Recipe:
NaOH -125g/L
Wetting Agent -12g/L
Seq. Agent -1g/L
Then ropes are passed through pre-wash boxes for three consecutive washes – cold wash, hot wash, and hot wash. The middle set of 6-8 boxes contain dye liquor consist of the stock vat, Hydrose, Caustic Soda, Wetting agent, Sequestering Agent. Generally, the stock vat is prepared by mixing the indigo dye with 0.7-0.8 time's caustic soda (solid) and 0.8-0.9 time's sodium hydrosulfite [15]. Then ropes pass immersed into a dye bath containing dye liquor at about 25 m/min for 20 to 30 seconds.

Indigo Dyeing Recipe:
Indigo (7.21%) -5 g/L
NaOH -5g/L

Hydrose	-1.5g/L
pH	-12
Temp (°C)	-27
Dip to Nip	-35 sec
Oxidation	-120 sec

Then squeezed ropes are oxidized by atmospheric oxygen for about 2 minutes with the help of skying rollers. This immersion-squeezing-skying remained the same for all dye boxes. In each box, some more leuco indigo is impregnated, and then air oxidation and thus indigo dye is successively built up, basically on the fiber surfaces[5]. Constant feeding of mother solution and automatic recirculation are necessary as per substrate weight to maintain dye bath concentration. Then three consecutive hot wash is given to the dyed rope to get was-out to unfix dyes.

2.3.2 Eco-Friendly Way of Dyeing

In this study, a new dyeing technique is achieved where two chemicals of Proser Chemicals, Adana, Turkey are used. This experiment was aimed to reduce wash boxes and eliminate continuous water flow in wash boxes. To achieve this 5 g/L Prosind WP-anionic surface-active agent-alone is used in the pre-wetting at room temperature.

Pre-wetting with Prosind WP Recipe

Prosind WP	-5 g/L
Temp (°C)	-Room
Dip to Nip	-35 sec

Owing to its low/zero foam development and good wetting action, Prosind WP ensures rapid de-aeration of yarns with Indigo dyeing at rope/ slasher/ loop system, with wound packages at long dye liquors and promotes penetration of the material by the liquor[16]. As there no caustic soda is used, no pre-wash is required. Then Indigo penetration is done followed by Premaclean WF-I reaction in an acidic bath. Premaclean WF-I is a multifunctional polymeric product for sulfur and indigo dyeing process, physically it forms a long polymer shield or chain that creates a ring form resin effect which blocks the lots of dyestuffs and accelerates the exclusive ring dyeing characteristics[17]. The dyed substrate is collected without any post-wash.

Premaclean WF-I Reaction Recipe

Premaclean WF-I	-15 g/L
Acetic Acid	-10 g/L
Temp (°C)	-75

2.3.3 Evaluation of Dyed Fabric Colorfastness

2.3.3.1 Determination of Colorfastness to Washing

Colorfastness to washing is determined by ISO 105 C06 method. Specimen and multifiber are cut into 10cm x 4 cm size and sewn. Washing liquor is made by distilled water, sodium perborate, ECE phosphate detergent. Then the sewn specimen along with 150mL liquor and 25 steel balls are put in can and washing is done for 40 min and 50°C as per the method. Fastness is assessed by greyscale after drying has done.

2.3.3.2 Determination of Colorfastness to Water

Colorfastness to water is determined by ISO 105 E01 method. Specimen and multifiber are cut into 10cm x 4 cm size and sewn. The sewn specimen is wetted by distilled water and then put into Acrylic Slides. Then it is kept in a perspirometer under 12.5kpa dead load. Then it is kept in the oven for 4 hours at 37°C. After drying, fastness is assessed.

2.3.3.3 Determination of Colorfastness to Perspiration

Colorfastness to Perspiration (Acid/Alkali) is determined by the ISO 105 E04 method. For making the acidic solution, sodium dihydrogen phosphate, L-Histidine monohydrochloride monohydrate, and sodium chloride along with distilled water are used. For alkaline solution, disodium hydrogen phosphate, L-Histidine monohydrochloride monohydrate, and sodium chloride along with distilled water are used. Then two specimens of 10cm X 4cm size swen with multifiber are soaked in the solution and then kept into the perspirometer by keeping into acrylic slides and giving 12.5 kpa load. Then it is kept in the oven for 4 hours at 37°C. After drying, fastness is assessed separately for acid and alkaline solution.

2.3.3.4 Determination of Colorfastness to Rubbing

Colorfastness to water is determined by ISO 105 X12 method where a standard rubbing machine is used. At first, specimens are cut. One is rubbed with dry rubbing cloth for 10 times and another is rubbed with wet (water 100%o.w.f) rubbing cloth for 10 times. Then fastness is assessed by greyscale and ratings are given.

3. Results and Discussion

3.1 Comparison of Color Fastness

Table 1 shows the result of the colorfastness test of dyed samples. It is seen that there is an improvement in all types of fastness tests. It clearly indicates better dye fixation to the substrate in the new dyeing process. While in traditional rope dyeing, 15-20 percent dyes are being washed out by post-wash.

SL. No.	Test for Colorfastness	Result			
		Conventional Dyeing		Eco-friendly Dyeing	
		Color Change	Color Staining	Color Change	Color Staining
1	Color Fastness to Washing	4/5	4	5	4/5

2	Color Fastness to Water	4	4/5	4/5	4/5
3	Color Fastness to Perspiration (Acid)	4	4	4/5	4/5
4	Color Fastness to Perspiration (Alkali)	4	4	4/5	4/5
5	Color Fastness to Rubbing (Dry)	2/3		3	
6	Color Fastness to Rubbing (Wet)	1/2		2/3	

Table 1: Colorfastness test results of both dyed samples

5.2 Comparison of Water Consumption

Hence, six wash boxes were bypassed during eco-friendly dyeing, there are a considerable amount of water is saved. The machine has run in 25 meters per minute speed and set length was 2000 meter. The machine was run for 80 min, therefore, 6000-liter flow-water is saved per rinse nozzle during the eco-friendly dyeing. Table 2 shows the water usage in every step of both types of dyeing. After calculation, it is seen that there are 60% savings in water usage during the total set of eco-friendly dyeing.

Process	Conventional Dyeing (L)	Eco-friendly Dyeing (L)
Pre-Wetting	2600	2600
Pre-Wash	21600	0
Dyeing	24000	24000
Post-Wash	21600	0
Premaclean Reaction	0	1200
Total	69800 L	27800 L

Table 2: Water consumption of various steps of both dyeing

Water-saving in eco-friendly dyeing

$$= \frac{69800-27800}{69800}\ x\ 100\%$$
$$= 60\%$$

5.3 Comparison of ETP Cost

60% less water usage in Eco-friendly dyeing also indicates a 60% less effluent load in ETP of dyeing mills (Table 3). So, there is a costing advantage per meter of denim fabric (Table 3).

Process	Total ETP cost (USD)	ETP cost per meter (USD)
Conventional	61.5	0.0308
Eco-friendly dyeing	24.5	0.0121

Table 3: Comparison of ETP cost per meter of fabric

5.4 Comparison of Chemical Cost

As there two new chemicals were introduced to the eco-friendly dyeing, there was a slight increment of chemical cost. Table 4 shows the breakdown of chemical usage in overall work. The chemical cost will increase by 23% in the new way of rope dyeing, however, considering effluent treatment cost, time and effort, overall dyeing cost increment is very low there.

Process	Total Chemical Cost (USD)	Chemical cost per meter (USD)
Conventional	598.3	0.30
Eco-friendly dyeing	732.56	0.37

Table 4: Chemical cost of dyeing

Chemical price increases $= \frac{0.37-0.30}{0.30}\ x\ 100\%$
$= 23\%\ (approx.)$

6. Conclusion

The main point of this study is reducing water consumption to produce denim fabric. Textile wet processing consumes most of the water of a textile mill. In denim mills, water consumption is higher than any other mills, because denim has two wet processes- one is warp yarn dyeing and another is washing (after it is sewn).

Approximately 150 liters water per kg fabric is utilized in a typical indigo dyeing process[9]. The weight of a pair of regular men's jeans is 1.5 to 2 kg. Most of the Bangladeshi textile mills are using underground water to dye and this water is drinkable. This study exhibits 135 to 180-liter water saving in a pair of jeans.

Eco-friendly dyed fabric shows good results in the colorfastness test. Denim manufacturers are frequently facing colorfastness problems in indigo and sulfur dyeing too. So, adopting new dyeing will help dyers.

The calculation indicates that the eco-friendly dyeing process will increase the fabric price by 16%. However, the FOB cost of a pair of jeans comprises shell fabric cost, pocketing fabric cost, trims and accessories cost, washing cost, CM cost and other. Fabric cost is holding approximately 47% of the total cost[18]. So, a pair of jeans having FOB USD 8.00 will rise up to USD 8.60, that is, a 7.5% increment in the overall price.

New generation customers are very much aware of environmental hazards, sustainability, sustainable supply chain, and corporate social responsibility. That is why retailers are now turning towards sustainable apparel production. So eco-friendly dyeing process can be a good concept for the sustainable apparel business.

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