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Sustainable Denim Washing by Process Optimization

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Abstract

Now-a-days sustainability is a crucial issue in denim washing. This research initiative is performed aiming to resolve the crisis of sustainability in denim washing by process optimization technique which highlights the reduction of water, chemical and time as well as costing of denim garments. In this research work, process optimization technique is administered by reducing several wash & chemical application baths into a single bath confirming without alteration of physical properties and color fastness of denim fabric. For confirmation without alteration of physical properties and color fastness, several tests are carried out like tensile and tear strength, color fastness to rubbing, color fastness to wash, color fastness to water, color fastness to perspiration and CMC (Carboxy Methyl Cellulose) value for both conventional and sustainable washing method. BOD, COD and pH of waste water is determined which shows better result in sustainable washing method also. Reduction of rinsing time in sustainable washing method results in less consumption of water by 475 and process time by 19% and also saves $0.34/ dozen garments which validate the cost effectiveness of this sustainable washing method.

Keywords

Sustainability, Denim Wash, Color Fastness, Cost Analysis

1. Introduction

Denim is a warp faced, indigo dyed, firm 2/1 or 3/1 twill weave fabric which is currently considered as a top fashion product for people of all ages especially to the youth due to its durability, fashionable and aesthetic look. Denim garment business gets supreme pace because of its indefinite variety of wash effects [1]. Washing is considered as one of the most widely used finishing treatments due to its appearance and comfortability to the wearers [2]. Denim washing process has a great impact on the environment which is why sustainability has become a major concern in recent times. A sustainable wash method by reducing wash baths will be able to reduce consumption of chemicals, water and time, which will enhance the denim community as well as washing industries all over the world [3]. L. Heikinheims *et al.* [4] worked on denim fabrics with Trichoderma Reesei Cellulases where he found Purified cellulase EG II is most effective at removing color from denim, producing a good stone washing effect with the lowest hydrolysis level. Arkady P. Sinitsyn *et al.* [5] experimented on application of microassays for investigation of cellulase abrasive activity and back staining where they want to present model microassays for testing the denim-washing performance and indigo deposition on garment pocketing fabric. A Sadeghian Maryan *et al.* [6] worked on introducing organo-montmorillonite instead of using pumice stone during washing to achieve old look appearance. In this study, desizing and softening operation was optimized. RM Tyndall [7] investigated on refining the smoothness and exterior look of cotton fabrics and garments by treatment with cellulase enzymes. They compared the use of cellulase alone and cellulase in combination with stones with regular stone washing. Naima Abdelfattah Haleb *et al.* [8] investigated the tactile properties of denim fabric in variance of four different types of washing i.e. caustic rinse at 60˚C, washing at cold bath for 30 min, washing at 60˚C for 60 min and stone wash. Ali Sadeghian Maryan *et al.* [9] researched on one step treatment with amylase or cellulose or laccase for a cleaner production of denim garment. They found that, the obtained color on the samples treated with the three enzymes had not been differed significantly with the bio-desized garment treated with cellulose or laccase and cellulase/laccase. Chi-Wai Kan [10] examined on CO_2 laser treatment as a clean process for treating denim fabric and a carbon dioxide (CO_2) laser was used for the color-fading treatment of denim fabrics. They observed that the color fading effect induced by CO_2 laser in denim fabrics was more effective than conventional cellulase treatment, if the processing parameters can be controlled carefully. A. Sadeghian Maryan *et al.* [11] synthesized silver nanoparticles in denim fabrics by silver nitrate reduction at cellulosic chain in presence of starch and/or glucose at alkali media. Ayanna Card *et al.* [12] studied the effects of repeated home laundering on the physical properties of washed denim fabric. Murat Tarhan *et al.* [13] studied the performance properties of denim fabric after applying several fading method i.e. sand blasting, laser and washing. Majid Montazer *et al.* [14] investigated the effect of different enzymatic treatment i.e. acid cellulases, neutral cellulases and combination of laccases with cellulases on denim garment. Martin Ortiz-Morales *et al.* [15] investigated on a comparative study of laser fading characteristics of denim fabric in variation of different types of laser. Abdur Rahman Telli *et al.* [16] researched on three types of denim yarn i.e. cotton fibers, recycled cotton fibers obtained from yarn wastes, and fibers produced from recycled PET bottles to produce denim fabric followed by enzyme and stone washing to find out washing performance based on several physical and mechanical properties of denim fabric. C.W. Kan *et al.* [17] studied the effect of repeated home laundering on stretch denim fabric. In this research they evaluated various performance properties of stretch denim fabric. Nazli Uren *et al.* [18] proposed recommendations to improve tactile comfort of denim fabric and also explored the competence of denim fabric in terms of low stress mechanical properties and sensory evolution. Shou Xiang Jiang *et al.* [19] illustrated an advanced textile design that is an amalgamation of laser engraving and foil lamination on denim fabric.

Several researchers have studied on the methods of washing but there is a research deficiency on process optimization of denim garment washing. This research work is performed by applying potassium permanganate spray on unwashed garments avoiding separate desizing process as well as maintaining same bath fixing, softening, pH control process which improves the water, chemical and time consumption successively creates a low cost denim garment which is cost effective and environment friendly.

2. Materials and Methods

2.1. Materials

Fabric Sample

100% Cotton 3/1 right hand twill fabric (10 s × 7 s) of 368 GSM with EPI 72, PPI 48 was used. The fabric was collected from Arvind (India), sewed in Denimach Limited (Bangladesh) to prepare denim long pant and washed in Denimach Washing ltd, Gorgoria, Masterbari, Gazipur, Bangladesh.

Dyes and Chemicals

Multiple chemicals were used in this research like as ULTERIOR PW-100I (Ulterion International LLC, USA) as anti-back-staining agent; MEGASOFT BBK (S & D Associates, Srilanka) used for softness and fullness of textile material; Glauber salt ($Na_2SO_4 \cdot 10H_2O$) (Faith International, China) used as an electrolyte. Potassium Permanganate (JAS chemical Industries, India) and Stable Bleaching Powder (Birala Chemical Industries, India) used as bleaching agent; ANTICREASE-256 (GDS Chemical Bangladesh (Pvt.) Ltd, Tejgaon, Dhaka, Bangladesh) used as an anti-creasing agent. GENZYME-MCS 90 (GDS Chemical Bangladesh (Pvt.) Ltd, Tejgaon, Dhaka, Bangladesh) used as a neutral cellulase enzyme; Sodium Metabisulphite (BASF, Germany) and Sirrix NE (Clariant International Ltd, Switzerland) used as a neutralizing agent; Direct Dye MODER DIRECT ORANGE K3R and MODER DIRECT RED BWS (Dysin International Ltd, Bijaynagar, Dhaka, Bangladesh) used as a tinting agent.

2.2. Methods

Here below mentioned **Table 1** denotes conventional washing process and **Table 2** denotes sustainable washing process. Both process undergo with 120 pcs

Table 1. Recipe of conventional washing method.

Steps	Process	Water (L)	Temp (˚C)	pH	Time (Min)	Chemicals	Doses	M: L
1	Desize	600	60	9	20	Anti-back staining agent	1000 gm.	1:10
						Stone	100 kg	
2 - 3	Rinse-2	1200	30		5			1:20
4	Enzyme	600	40	7	45	Cellulase enzyme	800 ml	1:10
						Anti-back staining	1200 ml	
						Stone	100 kg	
5 - 6	Rinse-2	1200	30		5			1:20
7	Bleach	700	50	10	15	Stable bleaching powder	5 kg	1:11
8 - 9	Rinse-2	1200	30		5			1:20
10	Neutral	600	50	7	10	Neutralizing agent	1 kg	1:10
						Anti-back staining agent	800 ml	
11 - 12	Rinse-2	1200	30		5			1:20
Hydro extractor & Dryer Operation – 2 times (after 1st wash 60 min + final wash 60 mins) 120 mins								
	Potassium Permanganate spray					Potassium permanganate	15 gm./l	
						Phosphoric acid	2 gm./l	
13	Neutral	600	50	7	5	Neutralizing agent	1.5 kg	1:10
						Anti-back staining agent	300 ml	
14 - 15	Rinse-2	1200	30		5			1:20
16	Tint	500	50	6 - 7	5	Direct dye (orange)	1 gm	1:8
						Direct dye (red)	350 ml	
						Glauber salt	1 Kg	
17	Rinse-1	600	30		3			1:10
18	Fixing	500	40		10	Fixing agent	500 ml	1:8
19	Rinse-1	600	30		3			1:10
20	Softener	500	30	6 - 7	3	Softener	500 gm.	1:8
21	pH controlling	500	30	5	3	Acetic acid	200 ml	1:8
	Total	12,300			147 min + 120 mins drying time = 267 mins			

Table 2. Recipe of sustainable washing method.

Steps	Process	Water (L)	Temp (˚C)	pH	Time (Min)	Chemicals	Doses	M: L
	Potassium permanganate spray					Potassium permanganate	30 gm./l	
						Phosphoric acid	4 gm./l	

Continued

1	Enzyme	600	40	7	55	Cellulase enzyme	800 ml	1:10
						Anti-back staining agent	1200 ml	
						Citric acid	300 ml	
						Stone	100 kg	
2 - 3	Rinse-2	1200	30		5			1:20
4	Bleach	700	50	10	15	Stable bleaching powder	5 kg	1:11
5	Rinse-1	600	30		5			1:10
6	Neutral	600	50	6-7	10	Neutralizing agent	1 kg	1:10
						Anti-back staining	800 ml	
7 - 8	Rinse-2	1200	30		5			1:20
9	Tint	500	50	6-7	5	Direct dye (Orange)	1 gm	1:8
						Direct dye (Red)	350 ml	
						Glauber salt	1 Kg	
10	Rinse-1	600	30		3			1:10
11	Fixing + Softening + pH controlling	500	40		10 + 3 + 3	Fixing agent	500 ml	1:8
				5		Softener	500 ml	
						Acetic acid	200 ml	
		6500			=119 mins + drying 60 mins = 179 mins			

garments (60 kgs). In conventional washing process we have to undergo with desize, enzyme, bleach, 2 neutralization, separate tinting, separate fixing, separate pH controlling, separate softening and 12 times rinsing . In contrast, In sustainable washing process we have to undergo with enzyme, bleach, 1 neutralization operation, tinting, same bath fixing, pH controlling, softening and 6 times rinsing. Desizing, 1 neutralization operation & six rinsing steps were completely avoided in sustainable process. Moreover, fixation, softening and pH controlling operation were performed in one bath.

Table 3 shows the different properties of fabric and standard method which have been used to measure that properties in this research work.

3. Results and Discussion

In conventional process at Table 4, there are more steps like individual desizing bath which have been skipped in sustainable washing. In sustainable washing, Potassium Permanganate was sprayed on the garments after dry process & then cellulase enzymatic treatment was done. By this process 1 neutral bath was saved. But in conventional process potassium permanganate was sprayed after base wash. Hence 2 additional neutral bath were required after potassium permanganate & bleaching treatment. After bleaching treatment only 1 rinse was

Table 3. List of test performed.

Properties	Standards and Instrument
Tear Strength	ASTM-D2261, HOUNSFIELD Universal Strength Tester
Tensile Strength	ASTM-D5034, HOUNSFIELD Universal Strength Tester
pH of the wash bath BOD, COD	ISO-3107, Mettler Toledo pH meter Manual Method
Shrinkage Test	AATCC-61A, Manual Method
CMC Test	Spectrophotometer Data color 600
Color fastness to Rubbing	ISO-105-X12, JAMES H HEAL electronic crock meter
Color fastness to Wash	ISO 105-C06, Gyrowash
Color fastness to water	ISO-105-E01, Gyrowash
Color fastness to perspiration	ISO-105-E04, JAMES H HEAL perspirometer

Table 4. Comparison between conventional and sustainable process.

Steps	Conventional process	Sustainable process Process Reduction
Desize	1 desize bath	No desize bath 1
Enzyme	1 enzyme bath	1 enzyme bath nill
Bleaching	1 bleaching bath	1 bleaching bath nil
Neutral	2 neutral baths	1 neutral baths 1
Tinting	1 tinting bath	1 tinting bath nill
Rinsing	12 baths	6 baths 6
Fixing, softener, p^H controlling	3 baths	1 bath 2
Total baths	21 baths	11 baths 10 baths

applied in leu of 2 rinses in case of sustainable washing. On the other hand, in conventional process fixing, softening and pH control were executed in separate bath but in sustainable washing all of prior mentioning operations were combined in a single bath. So finally, one desizing step, one neutral step, six rinsing steps, softening & pH control were skipped in sustainable washing process which was common steps in conventional washing process.

Tear and Tensile Strength

Typically, the tear strength was evaluated according to ASTM-D2261 method. The sample of 7.5 × 20 cm was inserted between one fixed jaw and another moveable jaw. Then 4.5 lb pressure was applied to warp direction and 4 lb pressure was applied to weft direction. Meanwhile moveable jaw is started to move by 300 mm/min. Jaw's motion is continued until sample is torn out. A computer is compiled to the instrument with relevant software which gives required reading of tearing strength. According to **Figure 1**, the tear strength for both warp & weft direction is comparatively good in sustainable washing process because less fibre degradation and less fabric friction happens in sustainable washing process.

Typically, the tensile strength was evaluated according to ASTM-D5034 standard. Here Crosshead speed of 10 mm/min and gauge length of 50 mm were maintained. The load was continuously applied to the 10 × 15 cm denim sample till it is fractured. The load and the corresponding extensions were recorded by the computer. According to **Figure 2**, the tensile strength for both warp & weft direction is comparatively good in sustainable washing process because less fibre degradation and less fabric friction happens in sustainable washing process.

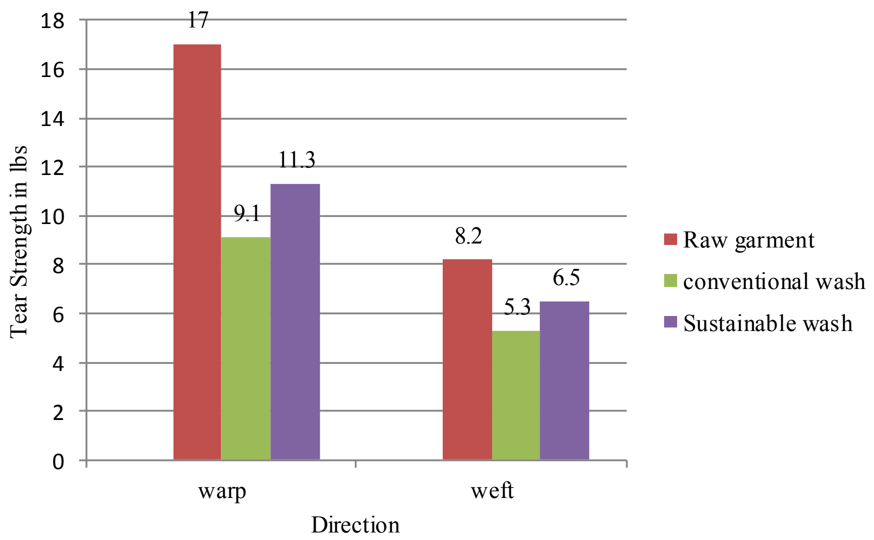

Figure 1. Tear strength test result of non-wash raw garment, conventional washed garment and sustainable washed garment in lbs.

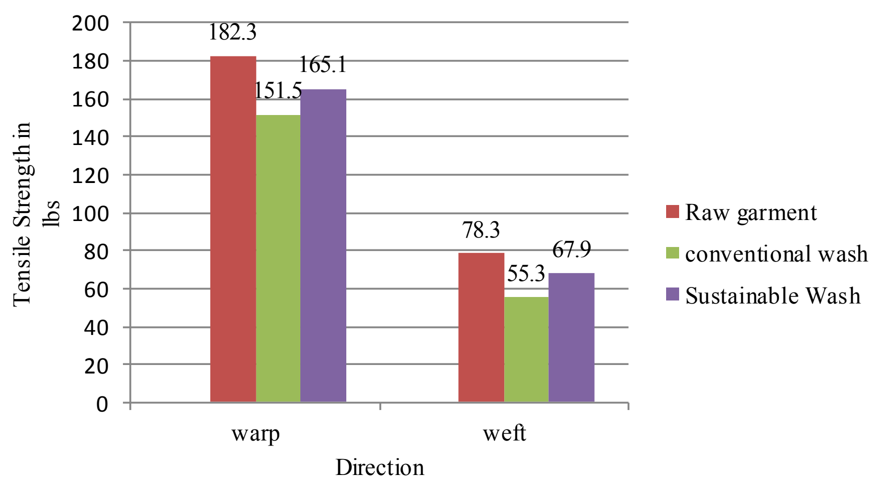

Figure 2. Tensile strength test result of non-wash raw garment, conventional washed garment and sustainable washed garment in lbs.

Color Fastness to Rubbing

Table 5 shows that color fastness to dry rubbing for both conventional & sustainable process is very good to excellent and wet rubbing grade shows significant staining. Although some processes have eliminated in sustainable wash process but identical result is achieved in both type of wash indicates the corroboration of sustainable wash.

Colorfastness to Perspiration

Table 6 and Table 7 show that the result of color fastness to perspiration in acid medium is same for both conventional and sustainable wash process which affirms no impact on colorfastness to perspiration for sustainable wash as there is no additional chemical or process is imparted in sustainable wash that validates the approach of sustainable wash technique.

Colorfastness to Water

Table 8 defines that for both conventional and sustainable wash process, color fastness to water is same. That means, the Colorfastness to water is not dependent on process elimination. In both process bleach process is done to match the shade. So there is no possibility of change of color fastness to water.

Colorfastness to Wash

Table 9 shows that in both conventional and sustainable wash process, color

Table 5. Staining on fabric (100% bleached cotton) for conventional and sustainable wash; Method: ISO 105 - X 12.

Washing Process	Rubbing fastness	
	Dry Rub	Wet Rub
Conventional Wash	4 - 5	2
Sustainable Wash	4 - 5	2

Here, 5 = Excellent, 4 = Good, 3 = Fair, 2 = Significant staining, 1 = Deep staining.

Table 6. Staining on multifiber in colorfastness to perspiration (acid medium) test for conventional and sustainable wash; method: ISO-105-E04.

Process	Color change	Color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Conventional Wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5
Sustainable Wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5

Table 7. Staining on multifiber in colorfastness to perspiration (alkaline medium) test for conventional and sustainable wash; method: ISO-105-E04.

Process	Color change	Color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Conventional wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5
Sustainable Wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5

Table 8. Staining on multifiber for conventional and sustainable wash; method: ISO-105-E01.

Process	Color change	Color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Conventional wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5
Sustainable wash	4 - 5	4	4 - 5	4	4 - 5	4 - 5	4 - 5

Table 9. Staining on multifiber for conventional wash and sustainable wash; Method: ISO 105-C06.

Process	Color change	Color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Conventional wash	4 - 5	3 - 4	4 - 5	3 - 4	4 - 5	4 - 5	4 - 5
Sustainable wash	4 - 5	3 - 4	4 - 5	3 - 4	4 - 5	4 - 5	4 - 5

change and color staining rating is same i.e. the colorfastness to wash is not changed for process skipping in sustainable wash.

CMC value of washed garments for shade matching

At Table 10, sample of sustainable wash process is compared with conventional processed garments in two different light sources i.e. D65 and F11. Table 10 shows value of CMC DE, DL*, Da*, Db*, DC* and DH* lies below 1. As a result, CMC decision is passed and shade is accepted for light source D65 and F11.

pH, BOD and COD value of denim garments after washing

According to guideline for the Assessment of Effluent, Dept. of Environment, Ministry of Environment and Forest, Bangladesh, June 2008 [20]: acceptable Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) range are 0 - 50 ppm and 0 - 200 ppm respectively. In comparison between two type of washing process, BOD and COD value is satisfactory for sustainable washing method. In conventional washing process, pH is not properly controlled that's why every step of washing bath shows higher pH value where as in case of sustainable washing technique, pH is controlled in early enzyme step. As a result, sustainable washing technique has become a proven environment friendly washing method (Table 11).

Shrinkage Test

Figure 3 shows that, in conventional washing process, the shrinkage% for both warp and weft direction is more in comparing with sustainable washing process. The reason of higher shrinkage in conventional process is its prolong washing time. So it is well defined that sustainable washing technique is more expected to avoid higher shrinkage of wash garment.

Fabric weight (GSM) Test

Figure 4 shows that the GSM of unwashed fabric is 368 gm/m^2 and after completion of washing, increment percentage of GSM is found as 9.2% and 6.5% for conventional and sustainable washing method respectively. Here sustainable

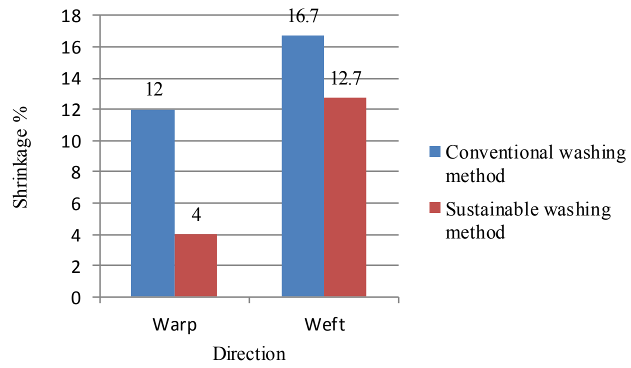

Figure 3. Comparison of shrinkage % between conventional and sustainable washing method.

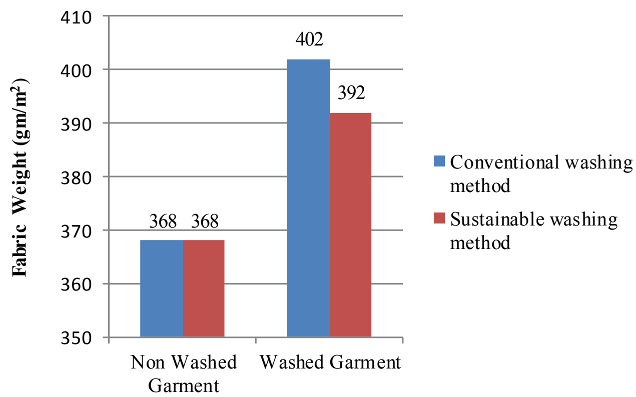

Figure 4. Comparison of fabric weight between conventional and sustainable washing method.

Table 10. CMC value comparison between conventional and sustainable wash.

Light/Observer	CMC decision	CMC DE	DL*	Da*	Db*	DC*	DH*	Metamarism Index
F11 10Deg	Pass	0.30	0.38	−0.12	0.19	−0.17	−0.15	0.05
D65 10Deg	Pass	0.30	0.37	−0.13	0.16	−0.14	−0.15	

Table 11. pH, BOD and COD value of denim garments for conventional and sustainable wash process.

Conventional process				Sustainable process			
Process	pH	BOD (PPM)	COD (PPM)	Process	pH	BOD (PPM)	COD (PPM)
Desize	8.8	76	212	Direct Enzyme	7.3	30	75
Enzyme	8.4	70	196				
Tinting	7.7	22	61	Tinting	7.2	21	59
Fixing	8.6	26	72	Fixing, Softener & PH control	6.7	41	110
Softener	7.6	42	117				
P^H control	7.3	66	184				
Liquor of (Tint, Fixing, Softener & pH Control)	8.9	44	123				

washing method is appreciated due to less increment percentage of fabric GSM which will reduce fabric consumption.

Cost calculation

Cost calculation is performed considering weight of garments 60 kg for 120 pcs garments. (Table 12 and Table 13)

Total save at sustainable process = 3480 − 3191 = 289 Tk. or \$3.40 per lot (120 pcs)

Per dozen saving = 28.9 Tk. or \$0.34 (1 US dollar = 85 Tk.)

Table 14 shows that, in sustainable washing method, almost 730 lots more denim garments can be washed in per year per machine by following sustainable washing technique which saves 730 × TK.289 = TK.210970 = \$2482. Total water saving per lot in sustainable process is 5800 L which saves 5800 × 730 × TK.024 = TK.101616 = \$1195 per year per machine. In sustainable process 47% water and 19% time is saved in per lot garments which makes this sustainable process more effective.

Visual Comparison

See Figure 5.

Figure 5. (a) Conventional (raw garment, desize and enzyme); (b) sustainable process (raw garment and enzyme); (c) clear view of color change for enzyme wash (conventional process-with desize and enzyme and sustainable process-without desize, and enzyme); (d) clear view of color change for bleach wash (conventional process-with desize, enzyme and bleach & Sustainable process-direct enzyme, bleach).

Table 12. Cost of conventional washing method.

Process name	Water Used (L)	Necessary chemicals	Amount (in Kg)	Rate (Tk/kg)	Cost (BDT)
Desize	600	Anti-back staining agent	1	120	120
		Stone	100 kg	17.8	1780
Enzyme	600	Cellulase Enzyme	0.8	475	380
		Anti-back staining agent	1.2	120	144
Bleach	700	Stable bleaching powder (Chlorine bleach)	5	43	215
Neutral (2 times)	1200	Sodium meta bi-sulphite	2.5	66	165
Tinting	500	Direct Dye	0.0014	2450	3
Fixing	500	Fixing Agent	0.5	450	225
Softening	500	Softener	0.5	150	75
pH controlling	500	Acetic acid	0.2	245	49
Potassium Permanganate spray	3	Potassium permanganate	0.045	690	31
		Phosphoric acid	0.006	120	1
Rinsing water used	7200 (12 × 600 L)				
Total water used	12,303 L			0.024 Tk/litre	295
Total cost					3480

Table 13. Cost of sustainable washing method.

Process name	Water Used (L)	Necessary chemicals	Amount (in kg)	Rate (Tk/kg)	Cost (BDT)
Enzyme	600	Cellulase enzyme	0.8	475	380
		Anti-back staining agent	1.2	120	144
		Citric acid	0.3	115	34
		Stone	100	17.8	1780
Bleach	700	Stable bleaching powder (Chlorine bleach)	5	43	215
Neutral bath	600	Sodium meta bi-sulphite	1	66	66
Tinting	500	Direct dye	0.0014	2450	3
Fixing + Softening + pH controlling	500	Fixing agent	0.5	450	225
		Softener	0.5	150	75
		Acetic acid	0.2	245	49
Potassium Permanganate spray	3	Potassium permanganate	0.090	690	62
		Phosphoric acid	0.012	120	2
Rinsing water used	3600 (6 × 600 L)				

Continued

Total water used	6503	0.024 Tk/lit	156
Total cost			3191

Cost of 1 liter water = 0.024 Tk (Source: Denimach washing ltd).

Table 14. Comparative cost analysis between conventional and sustainable washing method.

Name of process	Cost of per lot (USD)	Required water /lot (L)	Water Consumption Per day Per machine (L)	Time required for per lot (minute)	Production of lot per day per machine	Number of lot per year/machine
Sustainable washing method	39.88	6500	78,000	119	12	4380
Conventional washing method	43.5	12,300	123,000	147	10	3650

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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