



An Empirical Analysis of Sustainable Denim Washing Technology in the Apparel Industries

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Abstract: Over the last few decades, a lot of innovations and development works had already made denim “classic” in the fashion cycle. The modern consumers of today’s world are not only devoting themselves on clothing comfort but also emphasizing on economic and environmental sustainability. As a result, there has been increasing interests in terms of using environment friendly, non-toxic and highly biodegradable wet and dry process of denim washing technology, which is a combination of both the mechanical and chemical washing process. These are generally applied for denim garments and casual wearing. Without garment washing technology, apparels can’t draw proper attention on its end-users, just because it includes very few value added properties (such as hand feel, clothing comfort) with a view to attaining customer satisfaction. In addition, it improves the quality characteristics of apparels within low price margin. Some ecofriendly dry process of garments washing includes whiskering, hand sand, grinding, destroy effects. On the contrary, some wet process (such as enzyme wash, super white wash, bleach wash, acid wash, acid-stone wash, enzyme-stone wash and stone wash) utilizes very less amount of toxic dyes and chemicals. This research work simply made a general discussion related to the different types of garments dry and wet process. It also dealt with necessary apparatus, SOPs (Standard Operating Process), operational steps of sustainable and ecofriendly denim washing technology. Within limited global resources, it can help manufacturers and garments washing technologists to diversify the product and market of apparel trades.

Keywords: Garments Washing Technology, Sustainability, Ecofriendly, Dry Process, Wet Process, Clothing Comfort

1. Introduction

Denim, one of the ancient clothing items in today’s fashion industry, upholding its dignity and public acceptance even today within people around the world [1]. Its acceptance is increasing beyond age, gender, climatic conditions and social status [2]. A lot of innovations and development works in the last few decades had already made denim “classic” in modern fashion cycle till now [3]. The consumer expectations from denim fabric had changed over the years with technological enhancements. Nowadays, the modern consumers are not only devoted on infant designs and new appearances [4]; but also want to belong clothing comfort, user-friendly performance and consumer sustainability [5]. To meet the compatibility with the rapidly changing and strategic market conditions at growing customers’ demands

[6]; apparel technologists are now trying to introduce different infant variants of denim garments through physical and chemical modification of fabric’s morphology [7]. For instances, there has been increasing interests in environment friendly, nontoxic [8], fully biodegradable products with presence of garments washing technology [9]. Considering the following perspectives, sustainable and ecofriendly washing technology has already intended to modify the outlook, appearances and comfortability of apparel, by employing numerous physical, chemical and mechanical operations [10]. In the meantime, garments washing arrives with its lucrative ornamentation in textiles and apparels [11]. Beyond those value added outcomes [12], it also reduces unfixed chemicals, pigments and others insoluble matters from the fabric surface [13]. It goes without saying that garments are unhygienic to wear in absence of garments

washing technology [14]. The dry process of garments washing improves both the physical and structural properties of clothing items [15]. It enables nothing but an integration of whiskering, scrapping, grinding, tagging; whose are alternatively known as mechanical washing process [16]. On the other hand, the wet process includes hot wash, normal wash, enzyme wash, super white wash, acid wash, stone wash [17]. These enable surface modifications of textiles and apparels, just because of chemical treatments [18]. Numerous combination of physical and chemical operations is applied on garments surfaces according to the buyer imposed quality characteristics [19, 20]. The fast fashion trends are encouraging both the consumers and fashion brands to purchase quality clothing items at a reasonable price. As a result, this research work encouraged the deviation of garments dry and wet process at the denim fabric of same construction. Thus, it introduces different infant variants of denim garments in the competitive market of today's world. In addition, most of the time, there is a clear violation of SOPs (Standard Operating Process) regarding denim washing technology. Indeed, the analytical and experimental estimations of this research work may provide very few technical recommendations for the garments manufacturers and washing technologists. Those technical outcomes include process integration, selection of the most appropriate washing methodology, the right use of process variables and necessary chemicals while performing garments washing.

2. Basic Concepts of Sustainable Garments Washing Technology

The technology that is applied on garments with a view to developing new fashions & trends, improving ornamental appearance and comfortability of clothing items is simply known as garments washing. In normal understanding, washing simply indicates cleaning something dirty. But garments washing conveys a different meaning. It includes surface modification of textiles and apparels with the mechanical and chemical incorporation of washing process. It can be applied on either solid dyed garments or printed fabric. Generally, denim is nothing but a 2/1 or, 3/1 twill fabric with a dyed (either Sulphur or Vat) warp yarn and raw white weft yarn. During weaving of fabric manufacturing, size materials are applied on warp yarn, which strengthen the thread to withstand with mechanical abrasion in the loom. That's why it is imperative to minimize the stiffness of apparel in order to secure user-friendly experiences. To make fabric surface soft and smooth, garments washing technologists have been using some effective dry and wet process over the years. In addition, the mechanical processes are alternatively known as garments dry process, which combines whiskering, hand sand, grinding, destroy, 3D crinkle effect. It is generally applied onto unwashed condition, just before the 1st wash of textiles and apparels. Besides, it enables different types of mechanical abrasions and develops worn out appearance on fabric surface. Apart

from dry process, garments wet process such as enzyme wash, super white wash, acid wash, stone wash are applied on raw garments, with a view to removing the impurities (size materials, dirt, dust) of subsequent operations of textiles. Thus, it brings a new soft, smooth and worn out appearance in a comparison to an unwashed sample.

3. Sustainable Garments Dry Process

The operation of garments washing, which is done manually or mechanically with a view to changing the visual appearance of garments and add values [21], without altering the structural properties of garments is simply termed as garments dry process.

3.1. Sustainable Garments Dry Processes

- I. Whiskering
- II. Hand Sand
- III. Tagging
- IV. Destroy
- V. 3D Crinkle Effect
- VI. Grinding: Grinding can be performed by two instruments. Such as: (a) Pen grinding (b) Roller grinding

3.2. Process Flow Chart of Garments Dry Process

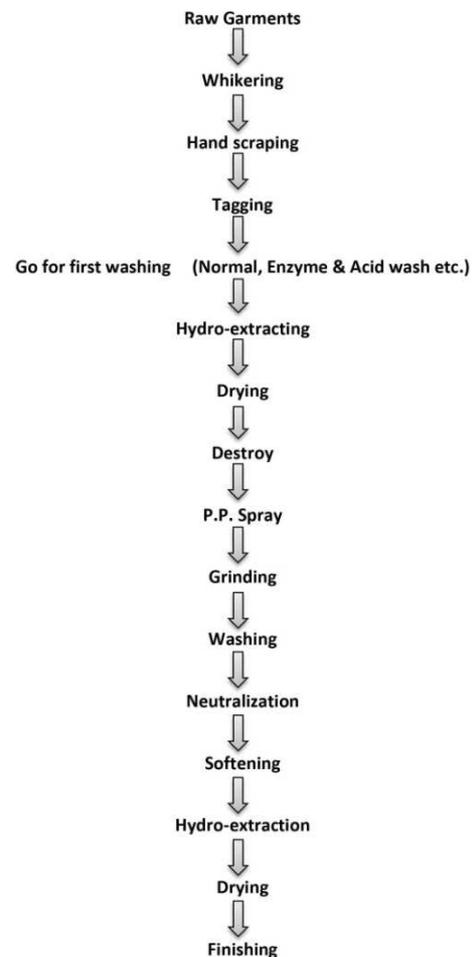


Figure 1. Operational flow chart of garments dry process

4. Garments Dry Process in the Apparel Industries

4.1. Whiskering

Whiskering is the first process and one of the most important operations in garments dry process [22]. Different whiskering pattern is developed according to the design. Generally, the garment is scrubbed over the prepared pattern with abrasive paper or emery paper to get the whiskered effect or fading effect.

It can be made in different ways, but the topmost ways are as follows:

1. By whiskering pattern
2. By manual hand scrap
3. By using laser machine



Figure 2. Sample manual whiskering

4.1.1. Apparatus

- a. Pattern
- b. Emery paper or abrasive paper
- c. Chalk powder

4.1.2. Process Flow Chart of Whiskering



Figure 3. Operational flow chart of manual whiskering

4.1.3. Operational Description of Manual Whiskering

Table 1. Stepwise process description of manual whiskering

Step No.	Operation Name	Figure
Step-1	Selection of raw garments	
Step-2	Pattern board selection (According to Buyer & Style No.)	
Step-3	Select emery paper according to the acceptable intensity	
Step-4	Pattern board insertion on leg panel	
Step-5	Whiskering on selected areas (Front pocket, Hip)	
Step -6	Quality check	

4.2. Hand Sand

Hand sand is applied after whiskering. It is performed with a view to ensuring worn out effect on denim garments. Abrasive paper, air dummy (horizontal), gum tapes are used. This process is highly used instead of sand blasting process, just because that is hazardous to health.

4.2.1. Apparatus

- a. Pattern
- b. Emery paper or abrasive paper
- c. Chalk powder



Figure 4. Hand sand on back part area of stretch denim.

4.2.2. Process Flow Chart of Hand Sand

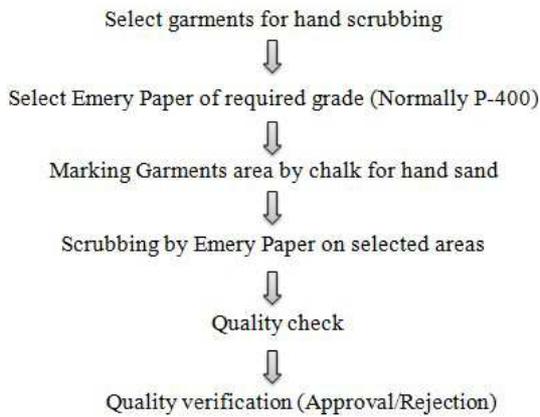


Figure 5. Operational flow chart of hand sand

4.2.3. Operational Process Description of Hand Sand

Table 2. Stepwise process description of hand sand

Step No.	Operation Name	Figure
Step-1	Selection of raw garments	
Step-2	Mark the area needed to scrub	
Step-3	Select emery paper	
Step-4	Start-up scrubbing on selected areas	
Step -5	Quality check	

4.3. Tagging

Tagging is the process that is done at the unwashed condition of garments [22]. After washing, visitors will get its effect. Maximum time, operators perform it at the edge areas, by folding the garments. Sometimes this process damages the garments by creating a hole.



Figure 6. Tagging on waist band area

4.3.1. Apparatus

- a. Tag gun
- b. Tag pin
- c. Chalk
- d. Hand Gloves

4.3.2. Process Flow Diagram of Tagging

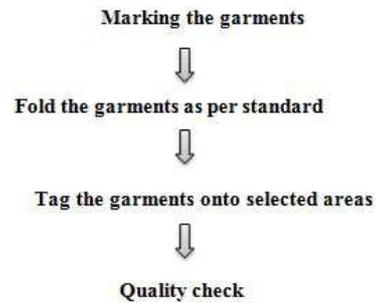


Figure 7. Operational flow chart of tagging

4.3.3. Operational Process Description of Tagging

Table 3. Stepwise process description of tagging

Step No.	Operation Name	Figure
Step-1	Selection of raw garments	
Step-2	Tagging onto selected areas	
Step -3	Quality check	

4.4. Destroy

Destroy is the most popular distressing method which is done by pen grinding machine with different size stones [22]. It looks like holes and worn out white yarns which make garments unique and fashionable.

4.4.1. Apparatus

- a. Grinding machine
- b. Grinding wheel
- c. Different size stones
- d. Needle
- e. Knife
- f. Electricity
- g. Safety accessories



Figure 8. Destroy effect

4.4.2. Process Flow Diagram of Destroy Effect



Figure 9. Operational flow chart of destroy effect.

4.4.3. Stepwise Process Description of Destroy by Pen Grinding Machine

Table 4. Stepwise process description of destroy effect by pen grinding machine.

Step No.	Working procedure	Figure
Step-1	Select the raw materials	
Step-2	Grind the specific area of the garments	
Step-4	Quality check of the garments	

4.4.4. Stepwise Process Description of Destroy Effect by Needle & Knife

Table 5. Stepwise process description of destroy effect by needle and knife.

Step No.	Operation Name	Figure
Step-1	Selection of raw Garments	
Step-2	Draw the design according to pattern card	
Step-3	Cut the warp yarn with the help of knife	
Step-4	Remove the cut yarn from the fabric surface	
Step-5	Quality check & verification	

4.4.5. Stepwise Process Description of Roller Grinding Machine

Table 6. Stepwise process description of destroy effect by roller grinding machine.

Step No.	Operation Name	Figure
Step-1	Selection of raw garments	
Step-2	Align onto a roller grinding machine	
Step-3	Quality check & verification	

4.5. 3D Crinkle

It is one of the important finishing treatments on denim garment which is applied after wet process. Bringing 3D effect on denim garments by treating with resins are called 3D crinkle. This process is done manually or semi automatically using resins like low formaldehyde or DMDHEU type resins which make crosslinks between cellulosic bonds and when the fabric deforms or folds or losses its normal orientation, those chemicals prevents the transformation to normal position and that causes wrinkles or creases. Various supporting auxiliaries are used for better penetration of resins and softeners used for softness.



Figure 10. Sample of 3D crinkle process

4.5.1. Techniques of 3D Crinkle Effects

- a. By 3D crinkle machine
- b. By Heat setting machine
- c. By Spray and chemical application cabinet with conveyer
- d. By 3D wire crinkle machine
- e. By 3D bendable leg or air dummy
- f. By using clip
- g. By garment crushing machine
- h. By tying garments with air

4.5.2. Apparatus

- a. Water
- b. Resin
- c. Supporting auxiliaries

4.5.3. Process Flow Chart of 3D Crinkle Effect

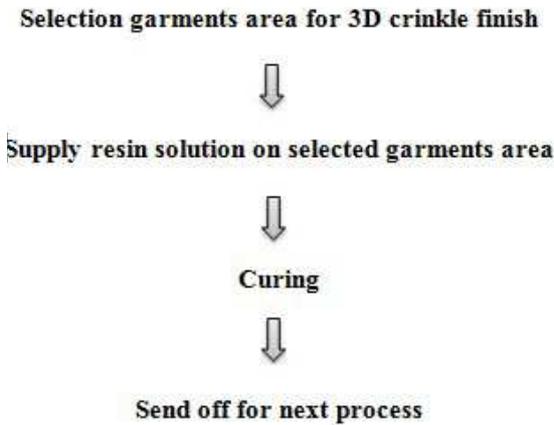


Figure 11. Operational flow chart of 3D crinkle effect

4.5.4. Stepwise Process Description of 3D Crinkle Effect

Table 7. Stepwise process description of 3D crinkle effects (Baked Effect)

Step-1	Selection of raw garments	
Step-2	Placement of garments on machine panel	
Step-3	Covering the garments with fabric	
Step-4	Provided heat at required time and temperature	
Step-5	Removing the garments from machine panel	
Step-6	Quality check	

5. Sustainable Garments Wet Process in the Apparel Industries

Garment wet process is a technology which is applied to change or modify the outlook, appearance, comfortability, and design of garments. Garment washing is applied on solid dyed garments or solid printed fabric.



Figure 12. On Going Operation of Garments Wet Process

5.1. Significance of Garments Wet Process

- a. To remove dirt, dust and waste materials from garments
- b. To remove size materials from garments
- c. To create color fading appearance
- d. To increase the brightness of garments
- e. To increase the smoothness of garments
- f. To make directly wearable after purchase
- g. To make garments become soft and handy
- h. To remove harmful materials from garments

5.1.1. List of Chemicals Used in Sustainable Garments Wet Process

- a) Enzyme
- b) Acetic acid [CH₃-COOH]
- c) Detergent
- d) Ant staining agent
- e) Bleaching powder [Ca(OCl)Cl]
- f) Sodium hyposulfite [Na₂S₂O₂]
- g) Caustic soda [NaOH]
- h) Soda ash [Na₂CO₃]
- i) Sodium bicarbonate [NaHCO₃]
- j) Cationic/ nonionic flax softener
- k) Micro emulsion silicon
- l) Salt
- m) Buffer
- n) Hydrogen peroxide [H₂O₂]
- o) Stabilizer
- p) Fixing agent
- q) Optical brightener

5.1.2. Types of Garments Wet Process

- a. Normal wash /Detergent wash
- b. Pigment wash
- c. Enzyme wash
- d. Stone wash
- e. Bleach wash
- f. Enzyme-stone wash
- g. Bleach-stone wash
- h. Acid wash

5.1.3. Tools of Garments Wet Process

- a. Sample washing machine (Horizontal / Vertical Type)
- b. Washing machine (Side loading)
- c. Washing machine (Front loading)
- d. Hydro extractor Machine

- e. Dryer machine (Steam)
- f. Dryer machine (Gas)
- g. Chemical mixture machine
- h. Industrial oven (Gas/Electric)
- i. Boiler
- j. Submersible pump
- k. Grinding machine
- l. Tagging machine
- m. Steam chamber for crinkle
- n. Sample washing machine (Horizontal)
- o. Sample washing machine (Vertical Type)
- p. Washing machine (Side loading)
- q. Washing machine (Front loading)
- r. Dryer machine (Steam)
- s. Dryer machine (Gas)
- t. Chemical mixture machine

5.1.4. Process Flow Chart of Garments Wet Process



Figure 13. Operational flow chart of garments wet process.



Figure 14. Super white washed stretch denim sample.

5.2. Wet Processes in Apparel Industries (Chemical Washing Process)

5.2.1. Super White Wash

Super white wash is a washing technique which is carried out in mainly for increasing the whiteness effects of stretch denim garments. It is done especially on the garments made from cotton grey fabric, mainly by using chemical like OBA (Optical Brightening Agent).

(i) Significance of Super White Wash

- a. To make the garments more whiten
- b. To improve the hand, feel of denim garments
- c. To remove size material from denim garments

(ii) SOP of Super White Wash

Table 8. Stepwise process description of super white wash

Process Name	Step Name	Chemical Name	Process Variable	Figure
SUPER WHITE WASH	STEP-1 (DESIZING)	DENIMCOL WASH-RGN=2g/L Bel. OET. TR (Stabilizer)=5 g/l	Quantity=60 piece Temperature: 60°C Time: 10 m. M: L=1: 8 Machine RPM=22	
	STEP-2 (BLEACH-ING)	NaOH = 4 gm/L H ₂ O ₂ =6 gm/L Biode 1 gm/L DENIMCOL WASH-RGN 1 g/L B-TEX (OBA) =0.5 gm/L	Temperature: 80°C Time: 50 m. M: L=1: 35 Machine RPM=20	
	STEP-3 (NEUTRAL-IZATION)	Acetic Acid=2 gm/litter	Temperature: 80°C Time: 50 m. M: L=1: 35 Machine RPM=22	
	STEP-4 (ENZYME WASH)	DENIMCOL-N 4 gm/L Biode 1 gm/L Acetic Acid=2 gm/l	Temperature: 45°C Time: 30 min M: L=1: 35 Machine RPM=22	
SUPER WHITE WASH	STEP-5 (SOFTEN-ING)	Bel. OET. TR (softener)=1 gm/l Acetic acid=2 gm/l	Temperature: 40°C Time: 10 min M: L=1: 35 Machine RPM=20	
	STEP-6 (HYDRO EXTRAC-TION)		Time: 5 minute Temperature: 25°C	

Process Name	Step Name	Chemical Name	Process Variable	Figure
	STEP-6 (DRYING)	-	Temperature: 80°C Time: 30 minute	
	STEP-7 (COOLING)	-	Temperature: 25°C Time: 20 minute	

5.2.2. Acid Wash

It is normally done on the garments from heavy fabrics like denim [23], course canvas and twill etc. Sometimes, acid wash incorporates with pumice stones. By the action of

pumice stones, irregular fading affect is developed on the garments surface [24-27]. The multi-layer fabric areas like – collar, pocket, placket, and side seam etc area will be brushed more than the single layer areas [28].



Figure 15. Acid washed denim sample

(i). Significance of Acid Wash

- To produce irregular fading effect or old looking effect.
- For soft feeling to wear the garments i.e. to improve softness.
- To increase rubbing fastness.

(ii). SOP of Acid Wash

Table 9. Stepwise process description of acid wash

Process Name	Step Name	Chemicals Name	Process Variables	Figure
ACID WASH	STEP-1 (DESIZEING)	Desizing Agent =1 g/L Detergent =1 g/L	Quantity=70 piece Temperature: 60°C Time: 20 m. M: L=1: 10 RPM=22	

Process Name	Step Name	Chemicals Name	Process Variables	Figure
	STEP-2 (HOT WASH)	Water =50 L	Temperature: 60°C Time: 5 minute M: L=1: 10 Machine rpm =20	
	STEP-3 (STONE WASH)	Acetic Acid=2 g/L	Temperature: 60°C Time: 3 minute M: L=1: 10 Machine rpm =20	
	STEP-4 (CLEANING)	Detergent=1 g/L	Temperature: 50°C Time: 10 minute M: L=1: 8 Machine rpm =22	
	STEP-5 (NEUTRALIZ-ATION)	Metabisulphite = 5 g /L	Temperature: 60°C Time: 5 m. M: L=1: 8 Machine rpm=20	
	STEP-6 (SOFTENING)	CH ₃ COOH=0.6 g/L Softener= 1 g/L	Temperature: 50°C Time: 10 m. Time=10 minute M: L=1: 7 Machine rpm=22	
	STEP-7 HYDRO EXTRACTION	Time: 5 minute Temperature: 25°C	Temperature: 25°C Time: 5 minute	
	STEP-8 DRYING	Temperature: 70°C Time: 30 min	-	



Figure 16. Enzyme washed denim sample.

5.2.3. Enzyme Wash

Enzymes are bio-chemical substances; those behave as catalysts toward specific reaction [29-32]. What makes very interesting the enzymes under a chemical point of view is

(ii). SOP of Enzyme Wash

their high specificity or in other words, their ability to attack selectively a given substrate [33-35]. The action of enzyme during enzyme wash, it hydrolysis the cellulose [36-37].

Mainly two types of enzyme used in Bangladesh.

1. Acid enzyme
2. Neutral enzyme

(i). Significance of Enzyme Wash

- a. For soft feeling to wear the garment.
- b. To increase the color fastness & rubbing fastness.
- c. Especially develop the "Bio-Polishing" effect of cotton/denim.
- d. To improve the anti-pilling properties.

Table 10. Stepwise process description of enzyme wash

Process Name	Step Name	Chemicals Name	Process Variables	Figure
ENZYME WASH	STEP-1 (DEIZING)	Desizing Agent 0.6 g/L Detergent 1 g/L	Quantity=45 piece Temperature: 60°C Time: 20 m. M: L= 1: 9 Machine rpm=22	
	STEP-2 (ENZYME WASH)	Acid Enzyme=1.5 g/L Acetic Acid=0.6 g/L Anti-staining agent =0.8 g/L	Temperature: 45°C Time: 60 m. M: L=1: 8 Machine rpm=18	
	STEP-3 (BLEACHING)	Bleaching powder=10gm/litter Soda ash=5gm/litter	Temperature: 60°C Time: 15m. M: L=1: 8 Machine rpm=22	
	STEP-4 (NEUTRALI-ZATION)	$\text{Na}_2\text{S}_2\text{O}_3$ =3 g/L	Temperature: 40°C Time: 12 min M: L=1: 9 Machine rpm=22	
	STEP-5 (SOFTENING)	Acetic acid=0.6 gm/litter Cationic Softener=1 gm/litter	Temperature: 50°C Time: 5 min M: L=1: 8 Machine rpm=22	
ENZYME WASH	STEP-6 HYDRO EXTRACTION	-	Temperature: 25°C Time: 5 min	
	STEP-7 DRYING	-	Temperature: 70°C Time: 25 min	

5.2.4. Stone Wash

Stone wash is done to produce fading and discolor effect on garments surface by stone [36-38]. In stone wash, stones are perforated and that are produced from volcanic explosion. This stones are also called pumice stone. The washing process is also applied on heavy fabric like denim and jeans to create aged and worn out appearance

(i). Significance of Stone Wash

- a. For achieving more fading or discolor effect to the areas where less brushing action takes place, there less discolor effect will be developed.
- b. For developing irregular fading effect in the garments by the action of pumice stones.

(ii). SOP of Stone Wash

Table II. Stepwise process description of stone wash

Process Name	Step Name	Chemicals Name	Process Variables	Figure
STONE WASH	STEP-1 (DESIZING)	Desizing Agent=0.6 g/L Detergent (Anti-Black Staining Agent) =1 g/L	Quantity=50 piece Temperature: 60°C Time: 20 min M: L=1: 9 Machine rpm=22	
	STEP-2 (HOT WASH)	Water=50 L	Temperature: 60°C Time: 5 min M: L=1: 9 Machine rpm =20	
	STEP-3 (BLEACH WASH)	Bleaching powder=10 g/L Soda ash=5 g/L Pumice stone=1/2 of garments volume	Temperature; 60°C Time: 15 min M: L=1: 8 Machine rpm=22	
	STEP-4 (NEUTRALI-ZATION)	Na ₂ S ₂ O ₃ =3 g/L	Temperature: 40°C Time: 12 min M: L=1: 9 Machine rpm=22	
	STEP-5 (SOFTENING)	Acetic Acid=0.6 g/L Cationic Softener=1 g/L	Temperature: 50°C Time: 5 min M: L=1: 8 Machine rpm=22	
STONE WASH	STEP-6 (HYDRO EXTRACTION)	-	Temperature; 25°C Time; 5 min	
	STEP-7 (DRYING)	-	Temperature: 70°C Time: 25 min	

5.2.5. Bleach Wash

Bleaching of garments means lightening the color of the indigo dyed garments and apparels are normally dyed with direct or reactive dye [39-40]. It is also a separate process, which can be applied instead of stone washing or together with stone

washing [41-44]. To avoid yellowing problems this process must be followed.



Figure 17. Bleach washed jacket

(i). Significance of Bleach Wash

- a. Partial color fading effect is produced
- b. Bleaching is also done after enzyme wash or with stone wash to get more fading effect or super light shade

(ii). SOP of Bleach Wash

Table 12. Stepwise process description of bleach wash

Process Name	Step Name	Chemicals Name	Process Variables	Figure
BLEACH WASH	STEP-1 (DESIZING)	Desizing Agent=0.6 g/L Detergent=1 g/L	Quantity=45 piece Temperature: 60°C Time: 20 m. M: L=1: 9 Machine rpm=22	
	STEP-2 (HOT WASH)	-	Temperature: 60°C Time: 5 m. M: L=1: 9 Machine rpm=20	
	STEP-3 (BLEACHING)	Bleaching Powder=10 g/L Soda Ash=5 g/L	Temperature: 60°C Time: 15 m. M: L=1: 8 Machine rpm=22	
	STEP-4 (NEUTRALIZ-ATION)	$\text{Na}_2\text{S}_2\text{O}_3=3 \text{ g/L}$	Temperature: 40°C Time: 12 m. M: L=1: 9 Machine rpm=22	
	STEP-5 (SOFTENING)	Acetic 2. Acid=0.6 g/L Cationic Softener=1 g/L	Temperature: 50°C Time: 5 m. M: L=1: 8 Machine rpm=22	
BLEACH WASH	STEP-6 (HYDRO EXTRACTION)	-	Temperature: 25°C Time: 5 min	
	STEP-7 (DRYING)	-	Temperature: 70°C Time: 25 min	

6. Conclusions

The opportunities and challenges related to the garments washing technology (dry and wet process) has been enlarging day by day. The following research paper simply analyzed ecofriendly, fully biodegradable and sustainable garments washing technology. Thus, it causes a lot of changes at physical, chemical, mechanical and thermal properties of clothing's. In the beginning of the 21st century, both the producers and consumers are intended to encourage environment friendly denim washing techniques. With the rapid changes in the clothing trends, consumers and fashion brands want to purchase quality clothing items at a reasonable price. This research work will help to diversify both the product and market of apparel trades within limited global resources.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest

All authors declare that they have no competing interests.

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