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Research Article

Superiority of Sustainable Ozone Wash Over Conventional Denim Washing Technique

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Abstract

Denim jeans need to be wet-processed in order to create a comfortable feel and a versatile look in the end product. The use of Ozone to finish denim jeans offers environmental and economic benefits by reducing rinse periods, water use, and energy consumption. Ozone is a specialized oxidant with a strong oxidation potential and can decolorize textile effluents, and it has a particular affinity for indigo. This paper will demonstrate why Ozone-based denim wash should be recognized as sustainable in different aspects of denim washing. The study observed that denim fabric finishing with Ozone particles has reduced garments processing time and requires less water and chemicals than the Conventional finishing method. Moreover, because of the low use of chemicals and water, ozone-based finishing produces a minimal amount of wastewater which eventually has less impact on the ETP as well as less effect on the environment than the traditional denim washing method. Also, it gives two times more production than conventional. With an in-depth evaluation of different washing points, this paper has concluded that Ozone-based wash is a promising finishing treatment for denim products.

Keywords: *Ozone, Denim wash, Sustainability, Garments Washing, Washing methods.*

1. Introduction

Denim garments have been seen a revival of interest among all age groups because of their worn-out look, modified appearance, and comfort. There are lots of technological factors that go into making denim one of the most iconic fashion items, such as huge improvements in spinning, washing, and finishing (Hoque *et al*., 2020). Applying different washing techniques brings a fashionable effect to the fabric, making the product exceptional and trendy (Hoque *et al*., 2018). But, these denim products aren't produced so cheaply as it looks like. In terms of yarn, an excellent export-quality denim garment requires a massive amount of qualities cotton yarn. Among them, ring spined yarn is quite common and mostly used because of its simplicity, flexibility, and economics in commercial production. But the problem is that these yarns are required huge amounts of fresh water and raw materials to produce denim garments (Parvez *et al*., 2021). Not only that, other than yarn, there are also have some factors like chemicals, electricity, or gas are needed to produce denim garments.

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Around 6800 liters of water is a prerequisite to growing enough amount of cotton to produce a pair of blue jeans. If we consider further industrial production processes, then it stands around 9400 liters (Fabcherrry, 2018). This means, in the conventional washing process, the amount of water we use is huge. So, we have to find out the best solution. And the best solution is ozone wash. In ozone wash, we can save not only water but also time, chemicals, and energy. Around 97.5% of the total water is saline, and 2.5% of water is potable. Only 3% of potable water is available in rivers, ponds, dams, or lakes, and 1% of water is entrapped underground. Gradually, the layer of entrapped water is going down, which is, of course, a major concern as this entrapped water is a primary water source of different industries.

Denim is the coarser yarn-based hard-wearing fabric with a high mass per unit area. Different kinds of denim washing techniques are done. In most cases, they are synthetic chemical-based on denim fabric or garments to make it soft and comfortable feeling along with fading effect to handle changing the garment's shade (Saiful Hoque *et al*., 2018).

Usually, enzymatic, bleach, stone, acid, etc., are such kinds of washing treatments widely used on denim garments. Among all types of washing treatment, Ozone washing always plays an important role in making a worn-out look on denim garments (Rashid *et al*., 2020).

Ozone wash is relatively new and substantially differs from the conventional method, have a clear picture of the history of the conventional method and its evolution over time. Surprisingly, no one knows when Acid washing was invented. The multinational denim company Levi Strauss claims that Donald Freeland, a worker at the Great Western Garment Company, invented the technique back in the 1950s. Garment washing has been used in many places across the world for the past 50 years. However, in Bangladesh, it started its journey in 1988. Gradually created space for denim wash. Denim washing is a technology that changes or modifies the appearance, size, comfort, and fashion of clothing and gives old garments-like effects. Varieties of chemicals and materials can be used to do the specific wash by the conventional wash method (Azam, Saleh, & Nafiz, 2016).

In denim washing, several wash effects can be achieved. The denim washing method is mainly divided into two-part- the wet process and the dry process. In the dry process, whisker, hand brush, grinding, destroy, crinkle, tag, tie, pp spray, etc., are inclusive, and in the wet process, desizing, enzyme, bleach, neutral, cleaning, tint is included. There are various conventional wash processes, like-Normal/Enzyme wash, Bleach wash, Enzyme Bleach wash, Stonewash, Towel wash, Acid wash, Super whitewash, etc. Because consumers have become more concerned about eco-fashion in the last decade, eco-friendly sustainable garment design has emerged as a new challenge for garment designers and manufacturers (Khan *et al*., 2013). The number of resources used in denim washing is ultimately determined by two critical variables: the desired end product and the procedures employed to achieve it. In line with the concerned consumers, producers thought about a new process that would reduce materials dependency in the aforementioned two processes. Consequently, ozone wash appeared in the scene, especially when the natural resources are finishing up so first. Ozone has that unique outcome for many denim manufacturing processes, and also possible to achieve the same design and properties of denim while saving water, energy, time, chemicals, and money.

Those advantages of Ozone in four broad areas:

1. While washing,
2. Wastewater treatment in ETP plant,
3. Improved end products,
4. Lower negative effect on the environment.

Ozone minimizes the amount of water and chemicals used in washing, and it generates less wastewater for ETP treatment, which is a distinct advantage. Furthermore, ozone-washed denim garments have higher quality parameters than conventionally washed denim garments. Because it readily oxidizes the dye molecules, Ozone is particularly effective in decolorizing textile effluents (Kamppuri & Mahmood, 2019). Ozone attacks the double bond of indigo dye, results in the breakdown of a double bond and produces the new compound. One is colorless, and another is a stem that looks yellow. These new compounds can react with denim fabric and produce the required color.

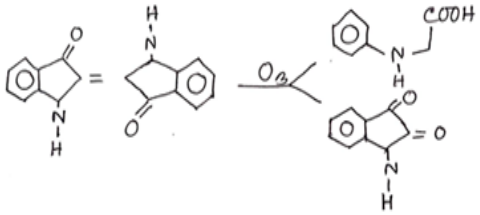

Fig. 1 Ozone reaction with Indigo dyes

2. Materials and Methods

2.1. Materials

The denim fabric is collected from the "Natural Denim Wash and Wear Limited" company's reserve and the fabric composition under consideration; Cotton (69%), polyester (26%), viscose (3%), and elastane (2%). The configuration of the fabric is 3/1 twill weave, and the average weight is 400 grams. And the required chemicals are from "Victory Bangla" dyes and chemical companies.

2.2. Methods

Mainly two different types of denim washing methods are available.

i. Conventional Denim Wash
ii. Newest Denim wash

However, there are some newly invented denim washing methods, but this paper only deals with the latest and sustainable friendly washing method named Ozone wash.

Before that, there is a short discussion about how these ozone gases are produced.

Generally, there are two methods to produce Ozone:

I. Ultraviolet method
II. Corona Display method

Corona display method is used mostly.

2.2.1. Conventional wash method

The traditional denim wash process consists of nine steps. Pre-treatment, Wash, Tinting, and Softening are the four major steps that cover everything. The discussion of the enzyme bleach wash method that can mostly be used in the denim washing industry. A strong oxidative bleaching agent is used during the bleach wash, either with or without pumice stones. The bleaching process decolorizes the dark blue shade by destroying the indigo dye molecules with oxidative bleaching chemicals. In the case of enzyme bleach wash,

first use the enzyme process, then the bleaching process using chlorine bleach. The shade of enzyme bleaching wash is light. Extra caution is necessary to make a good balance between fiber strength and more light denim fabric.

Fig. 2 Before Wash

Fig. 3 After Wash

Several chemical washes are applied to the denim. Added to that, there are substantial health concerns to the employees as a result of their exposure to the toxic chemicals used to spray on the material surface in pursuit of an 'acid wash.' The most commonly used reducing agent in alkaline reduction applications used in the conventional washing method is sodium hydrosulphite (Powar *et al*., 2020). When sodium hydrosulfite comes into contact with moisture, it oxidizes to hydrogen sulfite, sulfite, and hydrogen sulfate. In an acidic condition, sodium hydrosulfite may emit sulfur dioxide, which has been linked to respiratory irritation in humans (Schlottmann, 2004). In wet processing, a large amount of sodium hydrosulphite is typically used for color stripping (Powar *et al*., 2020). Those stripping chemicals cause damage to the textile (Yigit *et al*., 2018; Eren *et al*., 2016). The sandblasting process involves channeling fine sand into an air gun, which is then sprayed at high pressure onto denim to create a worn, old look. It is a cheap and quick method of manipulating garments, but its main ingredient, silica, is hazardous to workers and causes air pollution in factory premises. Improper waste management creates viruses and bacterial infections in the workers (Periyasamy, 2020). At the time of any denim process, the efficiency has never been achieved more than 85%, and the remaining chemicals stay with the wastewater, which occasionally dumps into the water body, turning into the indigo-blue colored polluted water like in the Burigonga River.

Apart from some technical difficulties and chemical hazards, conventional denim wash consumes a huge amount of water and chemicals. The chart below depicts water and chemical consumption:

Table 1 Conventional Process Materials Quantity

Resource Name	Water	Chemical	Time	Energy Consumption
Quantity	8800 liters	22.05 kg	110 min	18.5 kilowatt/hrs.

2.2.2. Ozone Technology-based Denim Shading

The sustainable ozone wash system aims to save chemicals, water, time, and energy used in denim wash. The growing awareness of the challenges raised has created a demand for alternative processes that can provide more resource-efficient shading in a safe and ecologically sustainable manner. Ozone wash is among the best in the sustainable wash category. The sustainable ozone wash process will give the garments the required outlook and bleaching effect for stone or laser wash garments.

Enzyme has emerged as a popular alternative to bleaching shading chemicals, offering benefits in terms of resource use and wastewater treatment. Another breakthrough has been the use of Ozone (O_3) in dedicated front-loading washing machines. Ozone is a powerful oxidizing agent that can bleach denim in a closed, batch-by-batch operation while also producing light, soft garments. It can also be used to simulate other denim finishing techniques, such as stone washing, with little effect on fiber strength. This process can fade jeans using a relatively lower amount of water or even no water. The technique also effectively resolves an issue known as "back staining," in which lighter weft threads get stained with dyes during processing, degrading the final look. The use of an ozone machine allows various processes to be integrated, which is a considerable advantage over a method that aims to substitute or eliminate chemicals in conventional processes.

2.2.3. Mechanism of Corona Display method

There are mainly four-cylinders used in this process. First of all, chamber one collects pure air from the environment and dispels other compounds from the air. Then chambers two and three collect pure Oxygen. Finally, chamber four produces Ozone from pure Oxygen, also called ozone generator.

$$3O_2 \rightarrow 2O + 2O_2 \rightarrow 2O_3$$

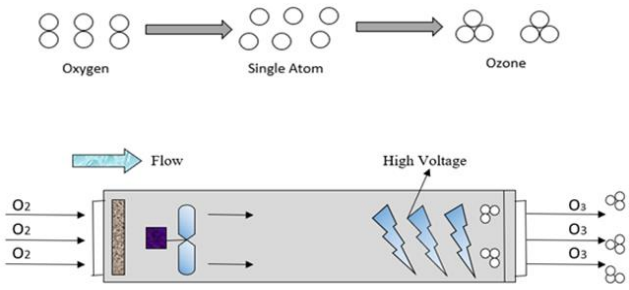

Fig. 4 Ozone Method

At first pure air is collected in a cylinder from the environment and then separates the pure Oxygen. Pure Oxygen is pooled into the ozone generator from the oxygen cylinder. A far accelerates Oxygen toward a high voltage area. High voltage is applied to Oxygen in this area, so the diatomic molecules break down into single

atoms and recombine to form an Ozone. Some of these recombined molecules contain three oxygen molecules instead of two. Thus, the powerful new compound ozone is formed and exists in the machine.

Fig.5 Ozone Washing Machine

The machine used here was a "Jeanologia eco G2e," from manufacturer Jeanologia, Italy, which has four chambers and was specially designed for ozone washing.

2.2.4. Ozone wash procedure

The ozone washing process is done as follows; in the first stage, the denim fabric sample runs for 40-45 minutes with detergent and desizing agent and enzyme, then hydro the fabric to remove excess water. After that, it dried with a dryer machine. But this wash is not compulsory; it can be done to acquire some specific shade and effect. The sample is placed into the ozone machine in the second stage, and the main process starts here. Choose Ozone at a 500 gm/hr rate, and the air pressure must be at or above 4 bar. After 20 minutes, check the shade. If the shade is ok, stop the machine and obtain the required design or effect—maximum 140 kg garments run by this machine at a time.

Table 2 Ozone Process Materials

Resource Name	Water	Chemical	Time	Energy Consumption
Quantity	2400 liter	2 kg	65 min	9 kilowatt/hrs

So, for running a complete Ozone washing process, each machine, "Jeanologia eco G2e." requires almost 9 kilowatt/hrs and nearly an hour of time. Most importantly, in most of the denim washing factories, these machine runs all the day except weekly maintenance day. Generally, all of the denim washing factories possed the same brand ozone machine.

Fig. 6 Before Ozone Wash

Fig. 7 After Ozone Wash

3. Results and Discussion

3.1. Chemicals & Auxiliaries

Ozone is capable of bleaching denim and reducing back stains without significantly reducing fabric strength. It bleaches denim in 15 minutes at optimum concentrations, compared to 30-45 minutes for traditional methods. As a result, Ozone increases production per shift. After finishing the process, the Ozone inside the washing machine is discharged through an ozone discharge unit, eliminating any toxic gas going to the atmosphere. The ozone monitor helps to detect any leakages for safety purposes. The finishing of ozone denim jeans provides environmental and economic benefits by reducing water and energy consumption during rinsing (Kamppuri & Mahmood, 2019). Besides, Ozone requires fewer intermediary steps (only two: Desize and Enzyme) compared to conventional ones (nine steps: Desize, Enzyme, Bleach, Neutral, Clear, Neutral, Tint, Neutral, Softener).

The following is a broader picture of why the ozone process is superior to conventional denim washing methods for a single batch (1 batch = 200 pieces = 80 kg).

Table 3 Required chemicals for Conventional wash

Chemical Name	Quantity	Chemical Name	Quantity
For Bleaching		For Neutral	
Na_2CO_3	500 gm	$Na_2S_2O_3$	2.5 kg
NaClO	12 kg	$Na_2S_2O_5$	1 kg
Bleach protector	200 gm	Lava Jeans Pro-80	735 gm
Enzyme		Ross acid	500 gm
G.B. ABS	400 gm	For Desizing	
Brodex Abra N-768	600 gm	Anti-Slipping agent	400 gm
Neoxil AAA	200 gm	Ross acid	400 gm
For Softener		For Tint	
LK-SD 329	400 gm	$Na_2SO_4.10H_2O$	1 kg
Evo Soft ELP	200 gm	M.D. Brown G.T.L.	13 gm
Neoxil AAA	200 gm	M.D. Red BWS	2 gm
For Cleaning			
H_2O_2		1 kg	

Here, Required chemical per batch = 22.05 kg
Chemical for one machine per day = 264.6 kg (12 batches per day in one machine)
Chemical for 37 machine per day = 9790.2 kg
Per piece required chemical = 0.11025 kg.

Table 4 Required chemicals for Ozone wash process

Chemical Name	Quantity
For Desizing	
Anti-Slipping agent	400 gm
Ross acid	400 gm
Neoxil AAA	200 gm
For Enzyme	
Brodex Abra N-768	600 gm
GB ABS	400 gm

Here, per batch required chemical = 2 kg
Chemical for 1 machine per day = 44 kg (22 batch per day in one machine)
Chemical for 5 machine per day = 220 kg
Per piece required chemical = 0.01 kg.

Table 5 Efficiency of Chemicals

Resource Name	Conventional Process	Ozone Process	Saving %
Chemical	22.05 kg	2 kg	90.93%

Around 91% of chemicals can be saved if we choose the ozone wash process over the conventional one.

3.2. Production

Consider this comparison of solid data from both conventional and latest ozone denim washing methods from a renowned factory that has transformed their entire denim production process into sustainable production methods.

Table 6 Efficiency of Production

Methods	Total production per hrs	Total Batches per day
Conventional	< 50 kg	12
Ozone	>90 kg	24
Efficiency	More than 40 kg	Double

It is noticeable that the two critical factors of production calculation are the quantity of production per hour and total batches per day. Total production per hour in conventional processes is less than 50 kg per hour, and in Ozone, it is more than 90kg per hour which is at least 40 kilograms efficient. Besides, in the latest ozone methods, the quantity of the total batches per day is as twice as conventional or 12 batches efficient per day.

3.3. Superiority of Ozone during wastewater treatment

Textile industries generate a massive amount of toxic effluent containing colors, sodium chloride, sodium sulfate, sodium hydroxide, and traces of other salts during the dyeing process. All of these chemical substances are produced as a result of dyeing and washing garment fabrics. When the wastewater containing these industrial effluents is discharged into different water sources, it may cause detrimental effects to the aquatic environment (Saiful Hoque *et al*., 2018). To assume the impact of these chemicals on the environment, we need to consider some water parameters, for instance, DO (Dissolved Oxygen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TDS (Total Dissolved Solids), and TSS (Total Suspended Solid).

Table 7 Comparison of ETP value:

Parameters	Standard (Max.)	Conventional	Ozone
Temp.	40°C	38°C	35°C
DO	4.5-8 mg/l	7.5 mg/l	6.18 mg/l
BOD	50 mg/l	42 mg/l	24 mg/l
COD	200 mg/l	122 mg/l	78 mg/l
TDS	2100 mg/l	1856 mg/l	1586 mg/l
TSS	150 mg/l	78 mg/l	11 mg/l

Table 6 Data clearly shows that the required temp of the ozone process is 5°C less than the standard value of 40°C and also less compared to the traditional process. Standard value of BOD & COD is about 50 mg/l and 200mg/l (maximum). If we use a conventional process, then the number of BOD & COD will be approximately 42 mg/l and 122mg/l, whereas that amount will further be lowered to almost 24 mg/l and 78mg/l, respectively in the ozone process, which is proof that ozone treatment is crucial for the ecosystem of river and canal. The ozone process shows a huge difference in the TSS value of only 11mg/l, whereas the conventional method value is 78 mg/l, which is almost half of the standard value of 150 mg/l.

Consequently, it opens a great opportunity for reusing the water for a past wash in dyeing and washing plants, which provides more profit margin for industry and gives a sustainable environment for animals and humans.

3.4. Efficiency of Water

Four renowned factories were selected who recently switched their washing methods from conventional to the latest ozone finishing method. Table 7 presents the data of water savings per kilograms production by comparing those factories' previous conventional methods data with the latest Ozone method data.

Table 8 Analysis of four renowned Bangladeshi Denim factories Water Efficiency

Name	Std.	Conventional (Liters)	O_3 (Liter)	Efficient (%)
Per Kilogram				
Natural Denim Wash & Wear	70 Liters	110	30	72.70%
Standard Group		67.7	19.3	71.49%
Soorty Textiles		90.5	21	76.80%
Hameem Group		137.5	37.5	72.73%
Per Piece				
Denim Wash & Wear	28 Liters	44	12	72.70%
Standard Group		50.75	14.5	71.49%
Soorty Textiles		63	14.6	76.80%
Hameem Group		63.5	17.3	72.73%

Based on data obtained from four prominent factories, the water-efficient ozone wash method is on average 73.44 percent more efficient than the conventional one. In terms of efficiency or production, everything is calculated in two ways: per piece and per kilogram usage. Whatever the approaches, the four-factory data indicate a minor variance of efficiency, demonstrating the data's strength as well as Ozone's superiority in water usage.

Here, Six consecutive conventional denim washing or finishing batches of water usage data were collected from an RD Jeans LTD Factory (Fully Conventional factory). Those data are analyzed below with government-provided standard data for better understanding. Here, in this specific analysis, no ozone wash data has been collected because table 8 already shows that Ozone uses not much water, not even cross the government-provided minimum standard level of water consumption.

Table 9 Analysis of water wastage percentage in the conventional wash

No. of Batches	Std. Water usage per piece in liter	Used per (In liter)	Waste per piece (In Liter)	Std. Water usage per kg (in liter)	Water Used per kg (in liter)	Water Wasted per kg (In liter)
1		44	16		110	40
2		39	11		105	35
3		42	14		107	37
4	28	46	18	70	111	41
5		43	15		109	39
6		44	16		110	40

On average, conventional washing generates 38.67 liters of water wastes per kilogram of denim. Whereas the standard water requirement is 70 liters, it consumes 108.67 liters of water to wash per kg, implying that nearly 35.5% of water is wasted. On the other hand, Ozone consumes only 40 liters of water, which is far less than the standard value of 70 liters, providing further evidence of ozone wash's water efficiency.

3.5. Efficiency of Energy & Time

The same machine has been used in all four factories from where data has been collected. As the amount of energy used in all the factories is the same, so the energy consumption of one factory is considered. The Tornello machine, which is used for the conventional process, requires 18.5 kWh of electricity per hour, and the Jeanologia machine, which is used for the Ozone process, requires 9 kWh of electricity per hour.

Table 10 Analysis of energy and production time

Average	Conventional Machine	Ozone Machine	Efficiency
Energy consumption per hour	33.92 kilowatt	16.875 kilowatt	50.26%
Required time per batch	110 min	65 min	40.90%

It surprisingly reveals that the latest ozone methods take half of the energy per batch and almost half of the time. Therefore, Ozone is 50.26% energy efficient and will save more than 1 hour per batch. Since the ozone process requires less energy & time, it can reduce shipment lead time directly related to lower labor cost and utility.

3.6. Test Report of Product

After both conventional and Ozone washing, two specimens have been taken to go through some tests to ensure product quality and performance. Here, in table 11, methods names of tests are presented, and table 12 shows the results and comparison between two different specimens.

Table 11 Test Methods Name

Tests Name	Methods
Seam Slippage	ISO 13936-2:2004
Color fastness to Rub	ISO 105-X12:2016
Color fastness to Wash	ISO 105-C08:2010
Resistance of Yarn	ISO 13936-2:2004
Tear	ISO 13937-1:2000
pH	ISO 307-2005
GSM	EN 12127:1997

Table 12 Specimen reports after washing

Tests		Standard	Ozone	Conventional
pH		4.0 – 7.5	5.8	5.5
Max force for Seam Slippage		120 N (>200 GSM)	120.28 N	114.62 N
Colorfastness to Rubbing		3-4	4	4
Color fastness to Washing		3-4	4	4
GSM (Gram per Square Meter)		390	388	383
Tear test	Warp	Mini. 15 N	30.30 N	28.91 N
	Weft	Mini. 20 N	49.05 N	48.5 N
Slippage resistance of Yarn test	Side seam	Maxi. 6 mm	2.5 mm	2.7 mm
	In seam		0.5 mm	0.6 mm
	Front rise		0.5 mm	0.55 mm
	Back rise		0.5 mm	0.5mm

After completing the lab test, we observed that in terms of the ozone wash product, a maximum force for seam slippage is higher than the conventional wash product. In the meantime, the tear test of the product shows impressive force intolerability in both warp and weft directions and also shows better performance in slippage resistance of yarn. The maximum possible value for all four parameters of the yarn slippage resistant test is 6. It is ideal if this number is as low as feasible. The total value in Ozone is 4.0, compared to 4.35 in conventional, demonstrating the durability of ozone-washed denim fabric. So, we can say that ozone-washed denim products can demonstrate good durable properties.

Conclusions

Ozone Based denim finishing is simple and environment friendly. Comparing the rest of the other latest known methods in the denim washing sector, Ozone is applicable beyond shading, such as in stone washing, to replicate other processes of denim finishing. The studies showed that Ozone wash is sustainable due to its high efficiency of water, chemical consumption. Moreover, it is comparably given minimal production costs and high production capacity. Since it runs in dry conditions, the system enhances whiteness and eradicates the back staining as well as other potential organic spots. In the end, there is no denying that conventional denim wash is going to be replaced by this new sustainable Ozone wash process due to its inherent superiority over conventional denim wash. Though it is believed that the lesser negative impact on the environment is due to decreased ETP discharge (chemicals and water), this article did not provide a comprehensive analysis on that topic. More rigorous research is required to understand the influence on the environment entirely.

References

Hoque, M. S., Hossain, M. J., & Rashid, M. A. (2020). Scopes of acid washing with varying concentrations of phosphoric acid vis-à-vis bleach wash. *Journal of Textile and Apparel, Technology and Management*, 11(2), 1–14.

Hoque, M. S., Hossain, M. J., Imtiaz, M. A., Das, S., & Rashid, M. A. (2018). Scope of Dry Wood and Wood Composite Alternate to Stone in Case of Acid Wash on Denim Fabric. *International Journal of Current Engineering and Technology*, 8(02). https://doi.org/10.14741/ijcet/v.8.2.32

Parvez, A. Al, Dutta, P., Shahid, M. I., & Akib, M. A. (2021). Analysis of the imperfection index (ipi) value of carded yarn produced by using different diameter spacers on the ring frame spinning machine. *International Engineering Journal For Research & Development*, 6(May), 1–7. https://doi.org/10.17605/OSF.IO/YZ5K3

Fabcherrry. (2018, June 1). Apparel Industry Combating Denim Water Use Problems. (earthbuddies) Retrieved

September 27, 2021, from https://earthbuddies.net/apparel-industry-combating-denim-water-use-problems/

Saiful Hoqe, M., Chakraborty, S., Hossain, M. F., & Alam, M. M. (2018). Knit Fabric Scouring with Soapnut: A Sustainable Approach Towards Textile Pre-Treatment. *American Journal of Environmental Protection*, 7(1), 19. https://doi.org/10.11648/j.ajep.20180701.14

Rashid, M. A., Hoque, M. S., & Hossain, M. J. (2020). Developing a New Hydrose Wash Technique for Treating Denim Fabric. *Journal of The Institution of Engineers (India): Series E*, 101(1), 11–18. https://doi.org/10.1007/ s40034-020-00161-6

Azam, M. S., Saleh, M. A., & Nafiz, K. A. (2016). Denim Wash. In An Introductory Knowledge About Garments Manufacturing Technology (pp. 281-294). Dhaka: Books Fair Publication.

Khan, M. M. R., Mondal, M. I. H., & Uddin, M. Z. (2013). Sustainable Washing for Denim Garments by Enzymatic Treatment. *Journal of Chemical Engineering*, 27(1), 27–31. https://doi.org/10.3329/jce.v27i1.15854

Kamppuri, T., & Mahmood, S. (2019). Finishing of denim fabrics with Ozone in water. Journal of Textile Engineering & Fashion Technology, 5(2), 96–101. https://doi.org/10.15406/jteft.2019.05.00189

Powar, A. S., Perwuelz, A., Behary, N., Hoang, L., & Aussenac, T. (2020). Application of ozone treatment for the decolorization of the reactive-dyed fabrics in a pilot-scale process-optimization through response surface methodology. *Sustainability (Switzerland)*, 12(2). https://doi.org/10.3390/su12020471

Schlottmann, U. (2004). SIDS Initial Assessment Reports for Sodium Dithionite (CAS No.: 7775-14-6) for SIAM 19. 1–128.

Yigit, I., Eren, S., & Eren, H. A. (2018). Ozone utilisation for discharge printing of reactive dyed cotton. *Coloration Technology,* 134(1), 13–23. https://doi.org/10.1111/ cote.12306

Eren, S., Gümüs, B., & Eren, H. A. (2016). Colour stripping of reactive-dyed cotton by ozone treatment. *Coloration Technology*, 132(6), 466–471. https://doi.org/10.1111/ cote.12240

Periyasamy, A. P. (2020). Environmental hazards of denim processing - III. Asian Dyer, 17(3), 43–47.

Saiful Hoque, M., Chakraborty, S., Hossain, M. F., & Alam, M. M. (2018). Knit Fabric Scouring with Soapnut: A Sustainable Approach Towards Textile Pre-Treatment. *American Journal of Environmental Protection,* 7(1), 19. https://doi.org/10.11648/j.ajep.20180701.14