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Effect of different washing methods on denim fabric properties and their effluent's environmental impact

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ABSTRACT

Nowadays, denim is in trend. To achieve visually appealing results, various washing processes are applied to denim. For washing denim, a variety of methods are available, and they all produce distinct kinds of waste. These methods have various environmental effects. This study aims to examine the environmental impact of various denim washing effluents. Here, six different washes desizing, enzyme, stone, bleach, acid, and random wash are performed. In order to compare how washing affects both the environment and the fabric, effluent tests are carried out. Since enzymes are unique by nature, enzyme wash demonstrated the greatest GSM. They don't affect the fibre composition; they just break down the color that is on the surface of the cellulose. Shrinkage is the cause of the general rise in GSM. However, the thickness, pilling, and elongation % of the cloth were unaffected by the washing. Due to the alkaline nature of the washing procedure, which results in minimal harm to the cloth, the enzyme and desize wash exhibit high strength. The fabric's rigidity decreases when stone, bleach, and acid wash damage it, which raises the angle at which the crease recovers. Due to the use of enzyme and desize wash produces effluent with a reduced TDS. In these procedures, the indigo hue on the denim surface is diminished, which causes the fading to occur. This process results in less polluted water that is simpler for wastewater treatment plants to process.

1. Introduction

The existence of life on Earth and the development of civilization both depend on water as a resource. The 2021 World Water Development Report, published by UNESCO, states that freshwater use has grown by around 1% year since the 1980s and has expanded six-fold over the past 100 years [1]. Water quality is having serious problems as a result of rising water use. Environmental deterioration and pollution brought on by industrialization, agricultural production, and urban life have a negative impact on the rivers and oceans that are essential for life, ultimately harming human health and long-term societal development [2]. One of the industries where people use the most water and cause the most pollution is the textile industry. The fashion sector generates 20% of the world's wastewater, and textile dyeing is the second-largest global polluter of freshwater. The biochemical and chemical oxygen demand (BOD and COD), photosynthesis, plant growth, and entry into the food chain are all significantly harmed by textile dyes [3]. The World Bank noted in its 2019 report "some studies have found that the textile sector is responsible for around one-fifth of worldwide water contamination. The textile business uses a lot of water since it is necessary for the bleaching and dyeing processes. Sadly, waterborne diseases claim the lives of roughly 3,575,000 individuals annually. Most of them include children and young people [4].

Water contamination occurs when chemicals contaminate water sources and render the water unfit for swimming, drinking, cleaning, or other uses. Chemicals, garbage, bacteria, and parasites are examples of pollutants. All types of pollutants eventually end up in water [5]. To create one pair of jeans, 500 gallons of water are needed. A pair of jeans consume 92% of the water footprint. The remaining water use is related to the fabrication of denim fabric. According to a World Resources Institute study, the manufacturing of clothing is responsible for 20% of all industrial water pollution worldwide, and dyeing methods are responsible for 85% of that contamination (an annual 1.3 trillion gallons). It is the responsibility of everyone in the chain, including government officials, cotton growers, denim manufacturers, denim designers, and end consumers, to reduce overall water consumption. There will be a sustainable cycle when everyone does their best [6].

Water is primarily used for two purposes during the wet processing of textiles. First as a chemical processing solvent, then as a washing and rinsing media. One of the crucial manufacturing pathways for addressing the ever shifting demands of the fashion market is denim washing. The washing techniques are used to alter the fit, level of comfort, look, and style of the garment. Different types of denim washes are being used for aesthetic and appealing looks. The processed water is the primary cause of pollution, particularly the polluted water, which contains a lot of contaminants such as, dyestuff (including indigo, sulphur, and other dyeing auxiliaries), solubilizing chemicals, buffer/pH controllers, electrolytes, and sizing components. Which are typically greater than the allowed limits. The pH, total dissolved solids (TDS), chemical oxygen demand (COD), and biological oxygen demand (BOD) of industrial effluent are all high (SS). The majority of these chemicals and colors are not easily biodegradable, which poses serious risks to human health and the environment.

The pH level of the water is one of the most important variables, impacting bursting strength performance; the lower the pH level, the less performance loss is observed [7]. The physical characteristics of denim after acid wash and stone wash are very different [8]. The enzyme treatment was carried out at different enzyme concentrations (50gm, 100gm, and 150gm) for 40 to 50 minutes. Enzyme-washed denim fabric was assessed for tensile strength, tearing strength, stiffness, and drapeability [9]. The enzyme-stone washing method has a big impact on the denim fabric's mechanical and physical properties. The characteristics of color are also somehow impacted. When the enzyme solution is increased and the amount of pumice stone is kept constant, the fabric weight rapidly falls while the other parameters stay the same [10, 11].

Above stated literature mentions studies regarding the performance properties but there is very limited study about the water quality of different washes so the motive of this article is to study the characteristics of the wastewater with respect to the various denim washes and to determine the influence of different washes on denim properties.

1.1 Experiment Work

1.1.1 Materials

Cotton is one of the most widely used fibers in the market due to its economic cost, ready accessibility without many restrictions, customer approval due to natural origin, and adaptability as a starting material for the development of new goods. The yarn used for the fabric manufacturing was ring spun yarn properties of yarns used are shown in Table 1 and Table 2.

Table 1

Yarn Properties

No	Parameter	Weft	Warp	Standards
1	Fibre	Cotton	Cotton	-
2	Linear density	8.00 NEC	8.00 NEC	ASTM D-1059
3	TPI	12.93 twists per inch	12.16 twists per inch	ASTM D-1422
4	TM	4.6	4.3	ASTM D-1423
5	Breaking Force	1186 gf	1164 gf	ASTM D-2256
6	Lea Strength	329 Lbs	305 Lbs	ASTM D-1578

Table 2

Washing Method and Chemicals

No.	Wash	Chemicals
1	Desize	Ultrazyme by Douglas Laboratory
2	Enzyme	Valvezyme by Douglas Laboratory
3	Stone	Pumice Stones by Intersac Denim
4	Bleach	NaOCl by Pulcra Chemicals
5	Acid	Stones and Potassium Permanganate by Hawkinsinc
6	Random	Rags and Potassium Permanganate by Hawkinsinc

1.1.2 Fabric formation

Fabric was woven on air jet Toyota 710 weaving machine. After that different equipment's were used for washing i.e Tumble Washer (Manufactured by Tonello), Hydro extractor Model no HG 120 (Manufactured by Yilmak HG 120) and Tumble dryer (Manufactured by Yilmak HBM 350).

1.1.3 Method

Desize Wash

First, a desize wash using a Tonello washing machine loaded with water in a 1:6 liquor ratio was performed. According to the prescribed liquor ratio, the tumble washer was filled with the desize (Ultrazyme 1%) and the anti-back Stainer. 1% of the fabric's weight was treated with anti-back stainer. The machine was loaded with fabric samples. Neutral pH and a temperature of 50 C were both maintained. After the desizing process, samples were rinsed in the machine for 10 minutes at room temperature.

Enzyme Wash

Second, water was added to the enzyme washer in accordance with our prescribed liquor ratio, which was maintained at 1:8. Once more, 1% of the fabric's weight was applied to the anti-back stainer, and 1:3 of the sample's weight was applied to the enzyme (1% Valvezyme). Then the fabric was placed into the machine. The machine was held at a neutral pH for 30 minutes while operating at 35 C. The sample was then rinsed with the solution for two minutes at room temperature.

Stone Wash

In stone wash, according to the appropriate liquor ratio water was put into the machine. The liquor ratio remained at 1:3. The pumice stones were then stored in a machine with 1% anti-back stainer after being soaked in Valvazyme. The pH of the solution was maintained at 7 while the sample was passed through the machine. The temperature was kept at 35^{o}C for 30 minutes. Rinsing of the sample with the solution was performed for 2 min at room temperature.

Bleach Wash

Samples destined to be bleach wash were first desized prior to the bleach wash, and one of them received enzyme treatment. Fabric type and anti-back stainer parameters were held unchanged. Sodium hypochlorite (NaOCl) solutions range in pH from 9.8 to 12.8 and in the amount of Cl_2 they contain, from 40 g/l to 160 g/l. In accordance with the prescribed liquor ratio, the machine was loaded with water. The liquor ratio remained at 1:10. The fabric was then fed into the appliance. Run the machine at 50 C for 10 minutes. After that, the sample was washed with the solution for two minutes at room temperature.

Acid Wash

Garment Washing machine was loaded with water in accordance with the prescribed liquor ratio for the acid wash. The liquor ratio remained at 1:6. Then, using the prescribed ratio of 1:3 and 3% on the weight of the fabric, pumice stones with $KMnO_4$ were inserted. The sample was introduced into the apparatus. 1% of the anti-back stainer was added. The samples were processed at 50°C for 10 minutes. The sample was washed with the solution for two minutes at room temperature.

Random Wash

Garment washing machine was loaded using the prescribed liquor ratio for random wash. The liquor ratio remained at 1:6. The machine was then loaded with 10 rags per garment containing 3% KMnO4. The sample was inserted into the apparatus. A 1% surcharge for the anti-back stainer was applied to the fabric's weight. The pH was maintained at neutral by running the machine for 25 minutes at 35̊C. The sample was then rinsed with the solution for two minutes at room temperature.

Table 3

Design of Experiment

Factor	Level 1	Level 2	Level 3	Level 4	Level 5
Washes	Desize	Acid	Stone	Bleach	Enzyme

1.1.4 Physical testing

The areal density of the fabric samples was measured according to ASTM D-3776. These samples' thicknesses were measured in accordance with ASTM D-1777.

1.1.5 Mechanical Test

Tensile Strength

The universal tensile strength tester Lloyd instruments NEXYGEN with material test and control software was used to test the tensile strength of each sample. The EN ISO 13934-1:1999 testing standard for cloth tensile strength was applied while applying the strip method.

Pilling resistance and Abrasion resistance

Martindale testers are used for testing pilling and abrasion resistance of all types of fabric structures. Samples were tested as per standard ASTM D-4966.

Crease Recovery Angle

The angle created by two fabric limbs of a previously folded strip under specific circumstances and at a specific period following the removal of the creasing force by a crease recovery tester in accordance with standard AATCC 66.

Effluent Test

The amount of particulate matter (small solid and liquid particles floating in water) is measured by TSS and TDS. These "solids" or particles can be separated into two groups by being run through a filter. Total suspended solids (TSS) are the particles that are large enough to be retained by the filter, whereas total dissolved solids are the particles that flow through the filter (TDS).

Table 4

Standards used to test effluent

Effluent Parameters	Equipment	Standards
pH	pH meter	ASTM D 1293-18
TDS	Photometer	ASTM D 5907-18
TSS	Meter	ASTM D 5907
COD	Dissolved oxygen meter	ASTM D 1252-06-2020
BOD	Dissolved oxygen meter	ASTM D 1252

2. Results and Discussion

2.1 Physical Properties

GSM

According to the results reported in Table 5, the total rise in GSM is owing to shrinkage [12]. Sample 3's enzyme wash revealed the highest GSM. Since enzymes are unique in their nature, the shrinkage that actually occurred could be the cause of the change in fabric weight. They don't affect the fibre composition; they just break down the color that is on the surface of the cellulose. Due to cellulose breakdown by KMnO4 and stone abrasion activity, sample 5 exhibits the lowest GSM. Fig. 11 displays the comparative analysis for GSM of various samples.

Table 5

Effect of different washes on physical properties

Sam. No.	Wash	GSM	Thickness (mm)	Strength (N)		Elongation (%)		Pilling resistance (Grades)	Abrasion resistance (Cycles)	Crease recovery angle (Degree)
				Warp	Weft	Warp	Weft			
Without wash		410.26	0.64	-	-	-	-	-		
1.	Desize	435	0.94	786	493	43	51.5	No Pilling Occurs (5)	30000-35000	254
2.	Stone	430	0.98	794	446	45.9	52.1	No Pilling Occurs (5)	35000-40000	260
3.	Enzyme	450	0.98	365	404	59.1	51.3	No Pilling Occurs (5)	35000-40000	235
4.	Bleach	432	0.98	610	360	48	57.1	No Pilling Occurs (5)	45000-50000	248
5.	Acid	422	0.98	335	519	52.9	43	No Pilling Occurs (5)	30000-35000	235
6.	Random	435	0.94	675	429	43.9	49.5	No Pilling Occurs (5)	30000-35000	258

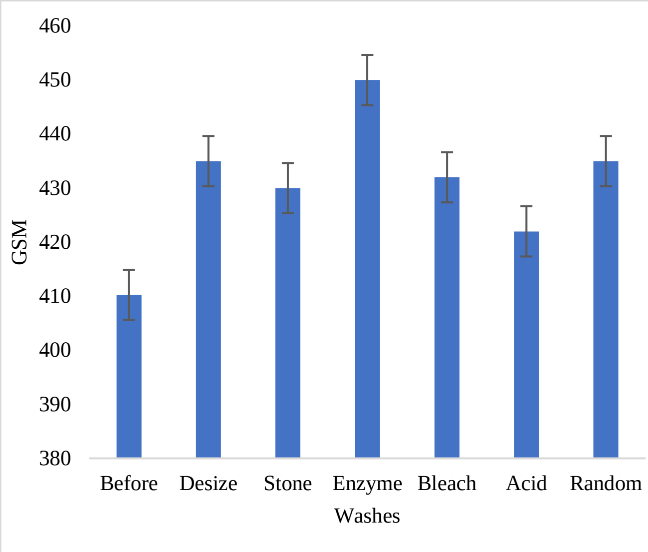


Fig. 1. Comparative analysis for GSM of washed samples

Thickness

It is clear from Table 5 that there is a slight change in thickness of the samples due to the shrinkage as the thickness of the fabrics increased [12]. The thickness of the fabric, however, was not significantly affected by the washing process. Fig. 12 displays the comparative analysis for sample thickness after washing.

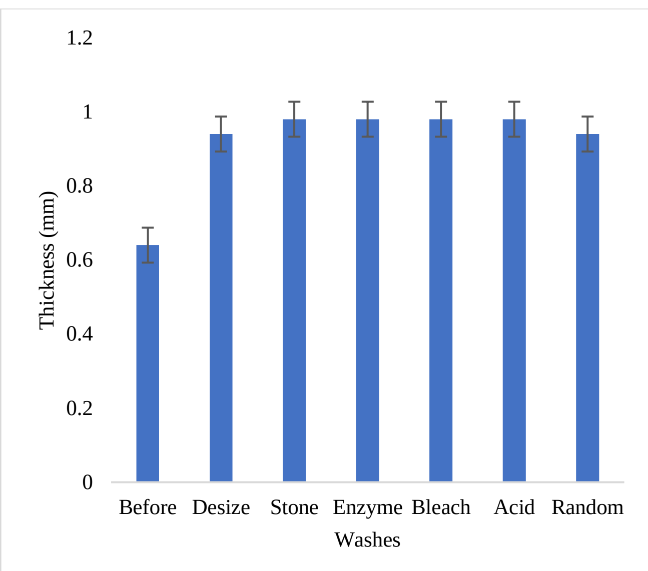


Fig. 12. The comparative analysis for thickness of washed samples

i. Physical tests

Breaking and elongation

A material's breaking strength is its capacity to sustain a pulling force. Table 5 displays the elongation and breaking strength of the samples. Due to the fabric's structure being harmed by numerous washes, samples 3, 4, 5, and 6 demonstrate less strength. These washings have an acidic activity that degrades the cellulose and lessens the fabric's tensile strength. Additionally, cellulose's surface fibres are destroyed by stone abrasion, reducing the material's strength. [13]. Due to the alkaline nature of the washing procedure, which causes minimal harm to the cloth, the enzyme and desize wash demonstrate great strength. Enzyme wash also has a biopolishing effect, which makes cotton stronger [12]. The washed samples elongation percentages showed no discernible change. Figures 13 and 14 display an analysis of these washes side by side.

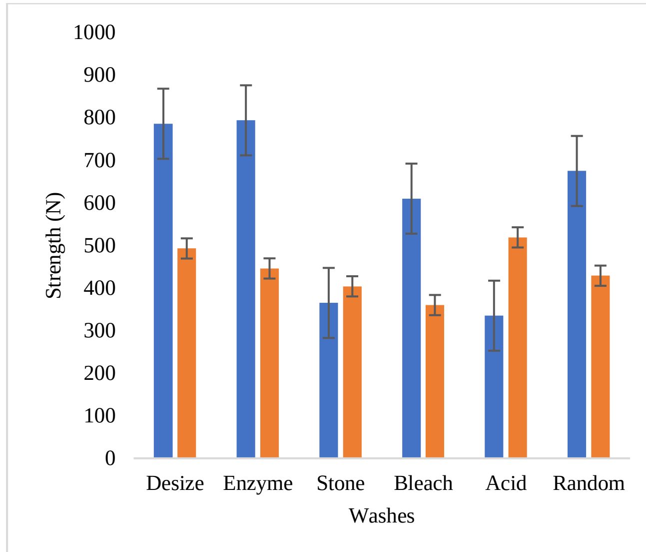


Fig. 13. Washed samples breaking strength comparison

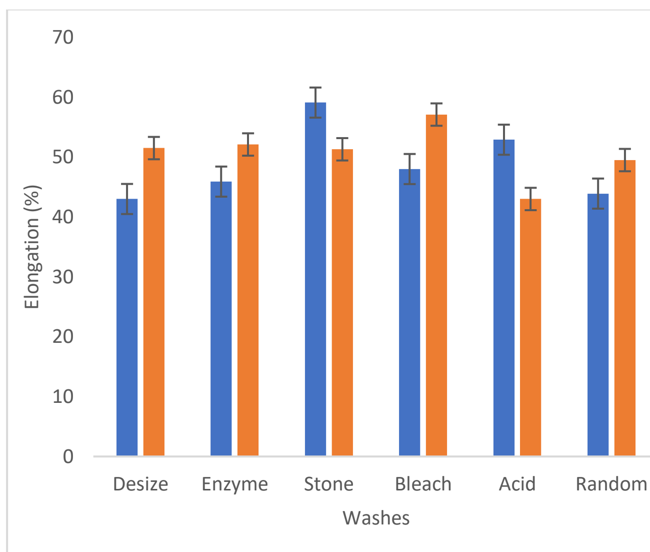
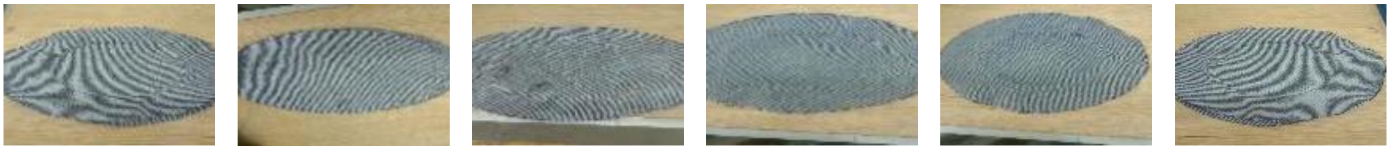


Fig. 14. Washed samples elongation comparison

Abrasion and pilling resistance

The compact fabric's structure and tightly wound yarns prevented any of the samples from showing pilling and abrasion for 1000 cycles, according to the data in Table 5 and the pilling photographic images in Fig. 15. After the washes, there was no discernible difference in the amount of pilling or abrasion of the fabric.



Desize wash Enzyme Stone wash Bleach Acid Random

Fig. 15. Pilling photographic images

All the samples are in good range of abrasion resistance

Crease Recovery

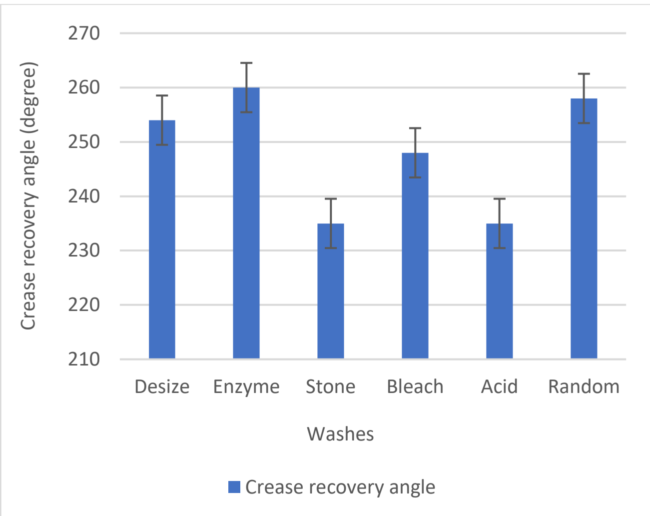


Fig. 16. Comparison of washed samples crease recovery angle

The fabric's resistance to creasing is demonstrated by the crease recovery angle. The fabric's stiffness and strength will determine its crease recovery angle. Table 5's results for crease recovery are displayed. As the fabric is harmed by stone, bleach, and acid washing, so is its stiffness. The acidic action of these washes causes the fabric to soften and become less stiff. Thus, the recovery angle for creases diminishes. Samples 3, 4, and 5 have the smallest crease recovery angles since their stiffness and strength have been reduced the most. The sample 1 and 2 does not significantly change as a result of the wash of alkaline composition [11]. Fig. 16 displays the comparison analysis for the angle of crease recovery for washed samples.

ii. Effluent Properties

pH

The pH of effluent for samples 1, 2, 3, 4, 5, and 6 is 7.4, 7.2, 7.1, 8.2, 6.9, and 7.6 respectively as shown in table 4. The fresh water is considered to have a pH of 6-8. The effluent of sample 5 has pH less than 7 due to the use of acid in it. Effluent of bleach wash has pH greater than 7 due to mild basic nature of NaOCl. The comparative analysis for pH of different washes is shown in Fig. 17.

Table 6

Environmental parameter values of different wash effluents

Sample No.	Wash	pH	TDS mg/L	TSS mg/L	COD mg/L	BOD
1	Desize	7.4	450	392	1458	714
2	Enzyme	7.2	510	254	198	97
3	Stone	7.1	550	368	1912	937
4	Bleach	8.2	750	13	54	26
5	Acid	6.9	600	18	96	47
6	Random	7.6	560	154	923	452

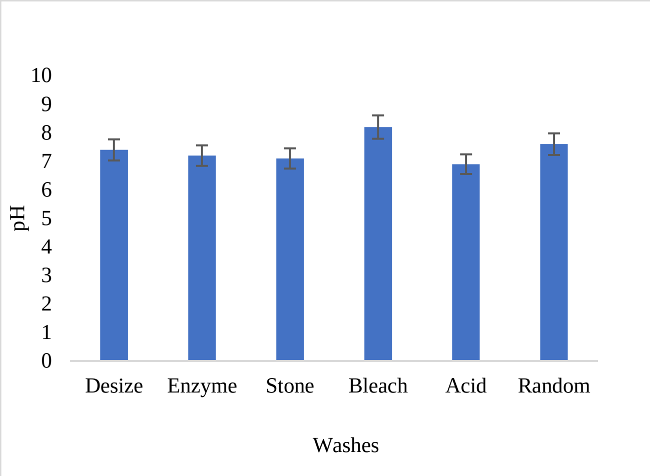


Fig. 17. pH comparison for various washes

The TDS in effluent of different washes are given in Table 6. Sample four showed more total dissolved solid than all other samples. It negatively affect the quality of water due to the inclusion of chemicals such as sodium hypochlorite, calcium hypochlorite and caustic soda because bleach washings are carried out in basic medium. More TDS are observed due to increase in hardness of the water by addition of NaOCl. The addition of Na to water contributes to an increase in TDS of water [14, 15]. Desize wash gives lowest TDS value due to the absence of metal ions in the product. The comparative analysis for TDS of different washes is given in Fig. 18.

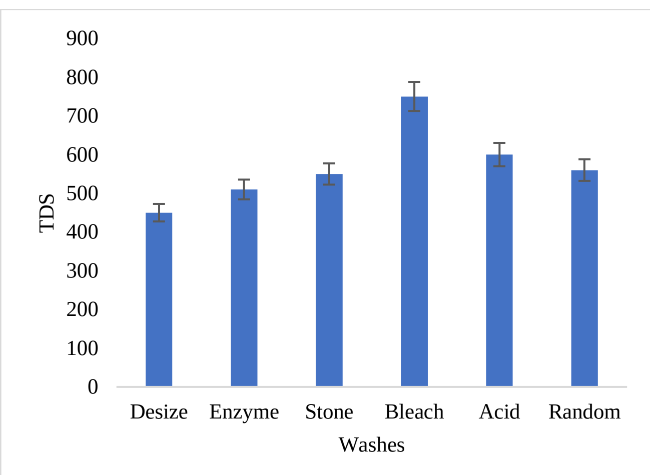


Fig. 18. TDS comparison from various washes

TSS

The TSS in effluent of sample 1, 2, 3, 4, 5, and 6 is 392, 254, 368, 13, 18, and 154 respectively as shown in Table 6. It was observed that the TSS in bleach and acid wash was lowest and in case of desize and stone wash was highest. The TSS in water is due to the undissolved solid material removed from denim during washing process [16]. The abrasive activity in desize and stone wash results in removal of solid material from cloth that results in higher TSS. The bleach and acid wash perform chemical reactions to degrade the material resulting in less suspended solid particles. The comparative analysis for TSS of different effluents is shown in Fig. 19.

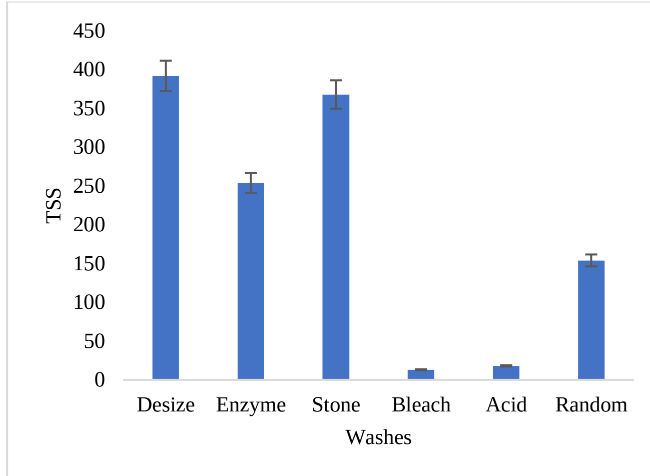


Fig. 19. TSS comparison in the effluent from various washes

COD

The COD for effluent of samples 1, 2, 3, 4, 5, and 6 is 1458, 198, 1912, 54, 96, and 923 respectively as shown in Table 6. Bleach, enzyme, and acid wash gave lower values for COD. The lower values indicate that the solid material is not removed during these washes as they are specific in action. The COD for effluent of stone and desize wash was highest. This was because of the reduction of solid material from fabric during washing processes. The oxygen taken by the material to chemically oxidize is called COD. Hence, the oxygen content for effluent received from desize and stone wash will be lowest. The comparative analysis for COD in effluent of different washes is shown in Fig. 20.

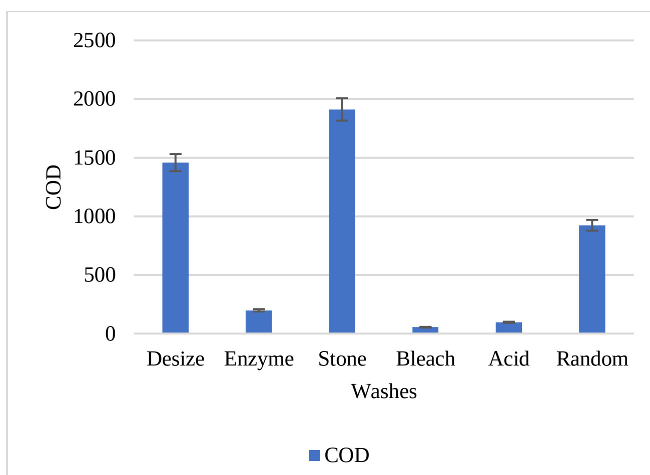


Fig. 20. COD comparison in the effluent from various washes

BOD

The BOD for effluent of samples 1, 2, 3, 4, 5, and 6 is 714, 97, 937, 26, 47, and 452 respectively as shown in Table 6. Bleach, enzyme, and acid wash gave lower values for BOD of effluent. The BOD for effluent of stone and desize wash was highest. Hence, the oxygen content for effluent received from desize and stone wash will be lowest. The BOD levels of these washes were same as the COD levels due to use of oxygen to oxidize the material removed during washing. The comparative analysis for BOD of the effluents is following in Fig. 21.

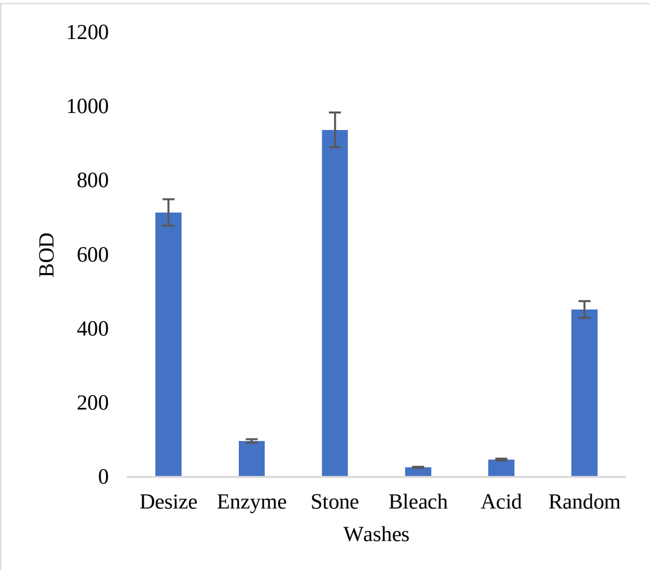


Fig. 21. BOD comparison in the effluent from various washes

3. Conclusion

Due to the specific nature of enzymes, the Stone washed sample had the highest GSM. They don't affect the cellulose's fibre composition; they just break down the surface-located dye. Due to cellulose breakdown by KMnO4 and stone abrasion activity, sample 5 exhibits the lowest GSM. However, the thickness of the fabric was unaffected significantly by the washing process. Due to the fabric's structure being damaged by numerous washes, samples 3, 4, 5, and 6 demonstrate decreased strength. Due to the alkaline nature of the washing process, the enzyme and desize wash exhibits high strength and does less harm to the cloth. Because of the compact packing of the yarns, the compact structure, and the fabric's pure cotton composition, no sample showed pilling after 1000 cycles. The samples 3, 4, and 5 have the smallest crease recovery angles since their stiffness and strength have been reduced the most. Because enzymes are used in both the desize and enzyme wash processes, samples 1 and 2 produce effluent with lesser TDS. In these procedures, the indigo hue on the denim surface is diminished, which causes the fading to occur. The effluent produced by this technology is less contaminated and easier to treat in wastewater treatment plants.

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