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Impact of Eco-Friendly vs. Conventional Scouring Methods on the Mechanical, Color, and Fastness Properties of Sequential and One-Bath Dyeing of Natural Fabric

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Abstract

The textile industry has significant negative effects on the environment, prompting this research to focus on finding solutions to prevent environmental contamination, especially in terms of air and water pollution. Due to its heavy reliance on water, energy, and harmful chemicals, traditional textile manufacturing contributes greatly to environmental damage. Sustainable scouring methods show considerable promise in addressing the issue of toxic chemicals. This study introduces an environmentally friendly scouring agent as an alternative to the conventional scouring process, which often employs hazardous chemicals that are detrimental to both the environment and human health. The proposed product's unique formulation eliminates the need for caustics during the bleaching process while also functioning as a washer, detergent, and peroxide stabilizer.
In this study, UNIV-AIO was utilized as an alternative to traditional scouring materials. It was applied in two different ways: first, as a scouring agent before the dyeing process, and second, as a scouring auxiliary within the dyeing bath itself. The results were compared based on the washing fastness properties and the tensile strength of the samples. The eco-friendly material yielded satisfactory results.

Keywords: conventional scouring, eco-friendly scouring, cotton impurities and direct dyes.

1. Introduction

Pure cotton fiber has a three-layer fibrous structure: the main wall, the secondary wall, and the lumen. Most of the non-cellulosic components are located outside of the cuticle layer of cotton fibers. A thin film that lies over the primary wall is called the cuticle. Soft surface grooves are present in the uppermost layer, which is primarily made up of waxes and lipids. ([1])
The main wall consists of both non-cellulosic material and amorphous cellulose, which has a cross-hatched arrangement of its fibers. As a result of the non-cellulosic and cellulose materials' unequal orientation, the surface of the primary wall is open and disorderly, giving the primary barrier flexibility. Esterified pectin molecules attach to both the main cell wall and the cuticle by means of cross-linking.([2]) The secondary wall is composed entirely of crystalline cellulose and is characterized by a dense packing of cellulose fibers organized in a parallel pattern. ([3])

To enhance the performance of raw cotton, all of these impurities and non-cellulosic components, including pectin, protein, waxes, minerals, and hemicellulose, should be eliminated. Also some necessary pretreatment processing are carried out like de-sizing, scouring, and bleaching. Cotton was made into a very absorbent fabric by isolating these wastes, which is required for bleaching, mercerizing, dyeing, printing, and finishing [4-5-6]. The fundamental objective of the cotton scouring process is to increase the absorbency of textile raw fabrics by removing non-cellulosic natural matter from the fabrics because such materials increase raw cotton's

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hydrophobicity and can turn it into a non-absorbent fiber ([7,8]). To remove hydrophobic materials from the primary wall, conventional scouring is carried out in an alkali solution with a high-temperature wetting agent and detergent [(9)]. To neutralize the use of high alkali concentrations, however, more water is needed.[3]

The drawback of caustic soda in conventional scouring: a) Cotton fibers are weakened by alkaline treatment, which causes swelling and attacks the secondary wall; b) Leeds conventional scouring to exceed cotton fabric weight loss guidance; c) Because the cotton fiber's waxy outer layer is totally removed after scouring, the surface becomes rougher, affecting yarn friction; and d) Using so many harsh chemicals boosts effluent water BOD, COD, and TDS levels during alkaline scouring. [(10-12)]

Recently, most of the environmental concerns in the textile sector have focused on reducing the use of hazardous chemicals, pollution, and wastewater in all industrial processes. Many attempts are made to accomplish this target by using an environmentally friendly agent as an alternative to the alkaline scouring process in place of sodium hydroxide treatment in conventional scouring. [(13)]

In an alkaline or neutral medium, direct dye is a group of dyestuffs that are applied directly to the substrate. Because of their widespread use and easy application and because they have a high substantivity for cotton, they are classified as anionic dyes substantial dyes for cellulosic materials. As implied by the name, direct dyes are applied without mordants. An electrolyte is added to an aqueous dye bath with dissolved dyes to aid in dying, which is then progressively heated to boiling. Without the aid of additional chemicals, the direct color molecules bind to the cotton fabric molecules. Although they are given vibrant colors, they have low wash fastness.[(14-15)]

This study provides a set of experimental results, discussion and comparison between the two processes of scouring (conventional and eco-friendly scouring) and then dyed with direct dyes.

2- Experimental Work

2-1- Materials

100% Egyptian cotton fabric (plain woven (1/1)), Weights of 140 g/m², a warp of 36 threads/cm and a weft of 34 threads/cm, both have a yarn count of 30/1. Was purchased from Misr-Helwan Spinning and Weaving Co., Egypt.

2-2- Chemicals

All used chemicals were of analytical grade,

Sodium hydroxide was analytical grade (Koch-Light Co.), Sodium chloride (LR grade), H_2O_2, (Koch-Light Co.), Univ-AIO is a pre-treatment auxiliary supplied by Sarex Chemicals, and its chemical characterization includes inorganic salts and oxides compounds, and the commercially wetting agent was the Triton X-100 1% supplied by Merck, Direct dye C.I. Direct Yellow 44 (SATURN YELLOW L4G 150) supplied by Synthesia chemistry .

2-3- Methods

2-3-1- Scouring Methods

Cotton fabrics were scoured using two different techniques (conventional and eco-friendly)

2-3-1-1-Conventional Scouring process

Cotton fabrics were treated with sodium hydroxide (4.0 %) and a wetting agent Triton X-100 1% using a liquor ratio (1:50 w/v) for 90 minutes at boiling. Then rinsing with hot and cold water and air dried at room temperature. [(15)]

2-3-1-2-Eco-friendly Scouring process

Cotton fabrics were treated with different concentrations of eco-friendly scouring agent Univ-AIO (1%, 2 %, 3%) and H_2O_2 50% for 70 minutes at 90ºC using a liquor ratio (1:50 w/v), then rinsed with hot and cold water, then air dried at room temperature.

2-3-2- dyeing process

Both scoured samples with (conventional and eco-friendly) methods were dyed using 30g/l of salt for 30 min at 90ºC for 45 minutes; the liquor ratio was 1:20, dye concentrations were (1%, 2% and 3%) (owf) C.I. Direct Yellow 44(SATURN YELLOW L4G 150)

2-3-3- eco-friendly scouring and dyeing in the same bath

Samples were treated and dyed in the same bath using different concentrations (1%, 2 %, 3%) of eco-friendly agents and different concentrations (1%, 2% and 3%) of direct dye. C.I. Direct Yellow 44 (SATURN YELLOW L4G 150)

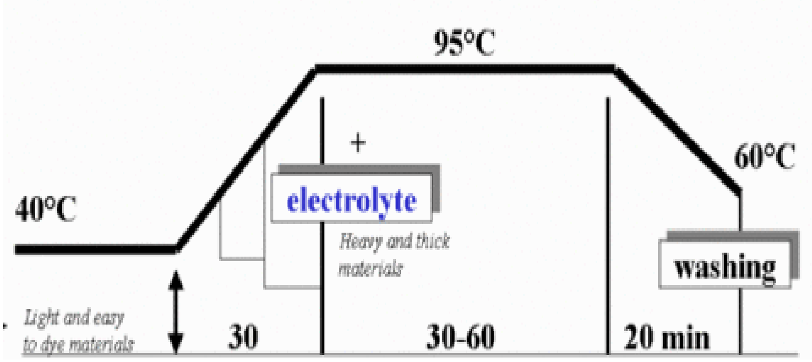

Figure (1): Dyeing procedure curve

2-4- Testing and Analysis

2-4-1 Color Strength (K/S).

The measurement was performed in accordance with ASTM E313 using CIE color system coordinates. Using this reflectance value in Kubelka Munk's equation, color strength (K/S) can be determined:

$$K/S = (1- R)^2 /2R$$

Where, R=Reflectance of an incident light from the dyed material, K=Absorption, and S= Scattering coefficient of the dyed fabric (2008). [16,17]

2-4-2 Color Fastness Properties.

Colour fastness properties of all dyed specimens were determined using the standard test methods :
Fastness to perspiration (ISO 105-E04:2013 Textiles — Tests for colour fastnessPart E04:
Colour fastness to washing: measured according to the (ISO) 105- C06 A2S: 1994 standards and AATCC test method 36- 1972).[18 -19]

2-4-3 Tensile strength.

The tensile strength (N) was measured using Zweigle testing machine, at a tension speed of 100 mm/min under the standard atmospheric. The testing was performed according to ISO 13934-1:2013(en) Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method. [20]

3 Results and discussion

3-1- color properties

3-1 -1-Effect of scouring types and dye concentration on the color strength (K/S)

A study examined the impact of different scouring methods on the color strength of cotton fabrics by dyeing them with three concentrations of direct dye. The data presented in Figure 1 shows that eco-friendly scouring methods generally yield higher K/S values compared to conventional scouring, regardless of the dye concentration. This suggests that textiles treated with eco-friendly scouring agents can absorb more dye or display better color intensity.

Eco-friendly scouring methods are likely to better preserve the fiber structure than harsher conventional processes that use strong alkalis. This preservation allows the dyes to penetrate the fabric more evenly and deeply. Furthermore, eco-friendly treatments may improve the fabric's surface morphology by increasing its porosity or swelling the fibers, which creates more sites for dye binding.
These factors enhance the fabric's ability to absorb dyes, leading to higher color strength, as indicated by the increased K/S values. It is also important to note that increasing the dye concentration consistently raises the K/S values, reinforcing the idea that more dye results in more intense colors.

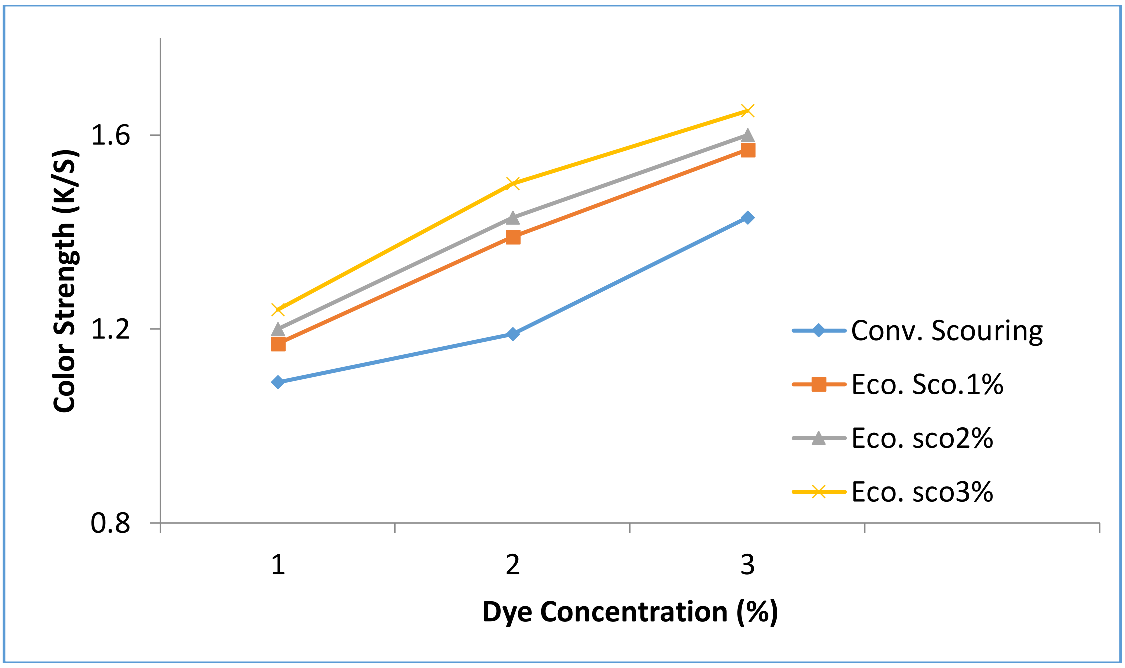

Figure (2): Effect of scouring agent types and dye concentration on the color strength (K/S) values.

3-1-2 Effect of concentrations of eco-friendly scouring and dyeing in the one- bath on K/S values.

Figure 2 illustrates the K/S values for textiles that have undergone both scouring and dyeing within the same bath. The eco-friendly scouring process was performed with varying concentrations (1%, 2%, and 3%), while the dye concentrations were also varied (1%, 2%, and 3%). It is evident that as the dye concentration increases, the K/S values rise across all levels of eco-friendly scouring. This trend suggests that higher dye concentrations lead to more intense colors, which aligns with the expected outcome that an increased amount of dye results in deeper color.

Considering the effect of scouring concentration, for a given dye concentration, an increase in the concentration of eco-friendly scouring agents leads to higher K/S values. This indicates that more concentrated scouring treatments enhance dye uptake or the effectiveness of dyeing, resulting in a more intense color. When comparing scouring and dye concentrations, at 1% dye concentration, K/S values increase from 1.94 with Eco. Sco. 1% to 2.06 with Eco. Sco. 3%. Higher concentrations of eco-friendly scouring agents thus result in more intense colors.

At 2% dye concentration, K/S values increase from 2.09 with Eco. Sco. 1% to 2.21 with Eco. Sco. 3%, showing a noticeable increase in K/S values with higher scouring concentrations. Similarly, at 3% dye concentration, K/S values range from 2.28 with Eco. Sco. 1% to 2.42 with Eco. Sco. 3% , Even at the highest dye concentration, a higher scouring concentration leads to the highest K/S values.

The data presented in Figure 2 clearly demonstrates that both higher dye concentrations and higher eco-friendly scouring concentrations lead to increased K/S values. When scouring and dyeing are conducted in the same bath, higher dye concentrations result in more intense colors, as reflected in the increasing K/S values. Additionally, higher scouring concentrations enhance the effectiveness of dyeing, as evidenced by the higher K/S values observed with more concentrated scouring agents.

In conclusion, using higher concentrations of both scouring agents and dye in the same bath produces the most intense color results. This suggests better dye uptake and possibly improved interactions between the dye and the textile.

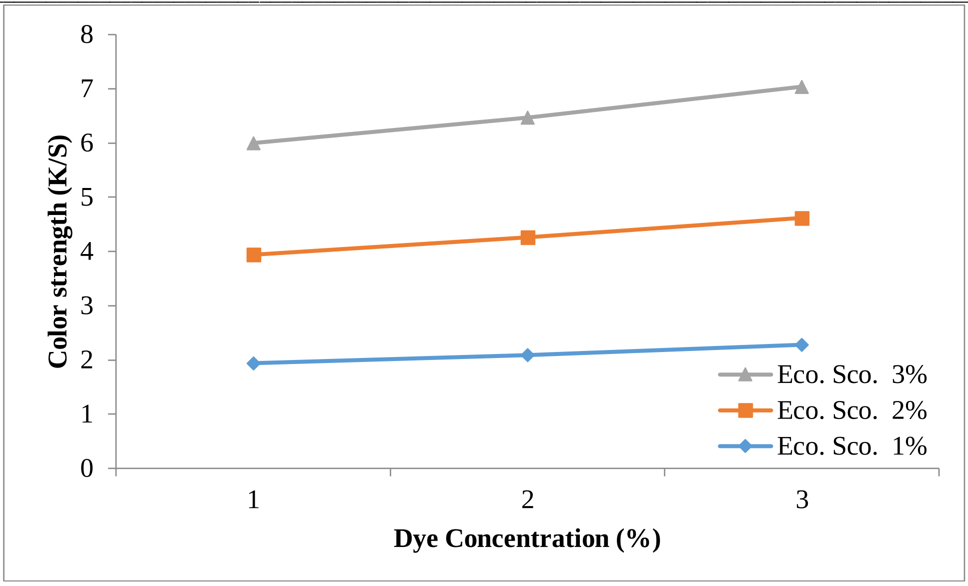

Figure (3): Effect of dye concentrations in one-bath with scouring agent on K/S values

3-2 Fastness properties

The data presented below outlines the fastness properties of cotton samples that were subjected to conventional and Eco. Scouring methods and subsequently dyed with varying concentrations of direct dyes. Fastness properties are essential for assessing the durability and stability of a textile's color under different conditions. The properties evaluated in this study include washing fastness and perspiration fastness, both of which are assessed based on alterations in color and staining. [3]

3-2-1 Effect of direct dye concentration on fastness properties on scoured cotton by conventional scouring.

The results of the washing fastness test, presented in Table (1), indicate that as dye concentration increases, there is a slight decrease in alteration fastness. This suggests that the fabric's color may degrade slightly with higher dye concentrations. However, staining remains unaffected, implying that while the fabric's color may change, it does not significantly impact the degree of staining on other fabrics.

Regarding perspiration fastness, the fabric demonstrates good fastness to cotton and varying levels of resistance to polyester under perspiration conditions. Higher dye concentrations tend to enhance resistance to both alkaline and acidic perspiration, indicating that the dye's resistance properties improve with increased concentration.

The results of the perspiration fastness test, shown in Table (1), reveal consistently high ratings (4/5) for cotton across all dye concentrations, indicating excellent fastness to perspiration. On polyester, the rating remains at 3, indicating moderate fastness to perspiration across all dye concentrations. Notably, the rating improves slightly from 3/4 to 3 as dye concentration increases, suggesting that higher dye concentrations may enhance resistance to alkaline perspiration. Similarly, the rating improves from 3/4 to 3 with increased dye concentration, indicating better resistance to acidic perspiration.

Table (1) Fastness properties of scoured fabric by conventional scouring and dyed with different concentrations of direct dyes.

Dye Conc. (%)	**Washing Fastness**		**Alkaline Perspiration Fastness**			**Acidic Perspiration Fastness**		
	Alt.	**St.**	**St. Cotton**	**St. Polyester**	**Alt.**	**St. Cotton**	**St. Polyester**	**Alt.**
1	3/4	3	4/5	3	¾	4/5	3	¾
2	3/4	3	4/5	3	3/4	4/5	3	3/4
3	3	3	4/5	3	3	4/5	3	3

Alt= Alteration, St= Staining. The rating on the grey scale (5 means no alteration or staining on the white adjacent fabric; 1 means high alteration and staining).

3-2-2- Effect of eco-friendly scouring and dyeing with direct dye on Fastness properties

Table (2) indicates that textiles treated with eco-friendly scouring methods generally exhibit high fastness properties when dyed with direct dyes. The alteration in washing fastness is typically rated at 4, with the highest ratings observed at increased scouring and dye concentrations. Staining ratings remain consistent at 3/4. Perspiration fastness shows excellent staining resistance on cotton and good resistance on polyester, with good to excellent alteration under both alkaline and acidic conditions, which improves slightly with higher scouring concentrations. Eco-friendly scouring either maintains or enhances dye performance, demonstrating its effectiveness in preserving or improving colorfastness.

Table (2): Effect of eco-friendly scouring and dyeing with direct dye on Fastness properties

Dye Conc. (%)	Scouring		Washing Fastness		Fastness to Alkaline Perspiration			Fastness to Acidic Perspiration		
	Type	Conc.	Alt.	St.	St. (Cotton)	St. (Polyester)	Alt.	St. (Cotton)	St. (Polyester)	Alt
1%	Eco. Scouring	1%	4	3/4	4/5	4	4	4/5	4	4
		2%	4	3/4	4/5	4	4	4/5	4	4
		3%	4	3/4	4/5	4	4	4/5	4	4
2%	Eco. Scouring	1%	3/4	3/4	4/5	3/4	3/4	4/5	3/4	3/4
		2%	3/4	3/4	4/5	3/4	3/4	4/5	3/4	3/4
		3%	4	3/4	4/5	4	4	4/5	4	4
3%	Eco. Scouring	1%	3/4	3/4	4/5	3/4	3/4	4/5	3/4	3/4
		2%	3/4	3/4	4/5	3/4	3/4	4/5	3/4	3/4
		3%	3/4	3/4	4/5	4	4	4/5	4	4

Alt= Alteration, St= Staining. The rating on the grey scale (5 means no alteration or staining on the white adjacent fabric; 1 means high alteration and staining).

When comparing between tables (1) and (2) it is found that total improvement: Eco-friendly scouring consistently provides better or equal performance in fastness properties compared to conventional scouring. It improves washing fastness alteration and staining, and enhances perspiration fastness across various conditions .**Cotton**; Fastness properties remain consistently high across both tables, unaffected by the type of scouring. Polyester, Shows a significant improvement in fastness properties with eco-friendly scouring, indicating that eco-friendly methods enhance polyester's resistance to washing and perspiration. Alkaline and Acid Perspiration, Fastness ratings are generally improved with eco-friendly scouring, demonstrating better performance under these conditions. These results may suggest that eco-friendly scouring can alter the surface morphology of fibers. It may increase surface hydrophilicity, which enhances water absorption and swelling, ultimately improving dye bonding. In contrast, conventional scouring often uses harsh chemicals, such as strong alkalis, which can damage the fiber structure. This damage leads to weaker interactions between the dye and fibers, resulting in reduced fastness properties. Eco-friendly methods are milder and help preserve the integrity of fibers, ensuring that the dye is more securely anchored to the fabric. This preservation of fiber strength and structure also enhances the fabric's resistance to washing and perspiration.

3-2-3- Fastness properties of samples scoured by eco-friendly scouring and dyed with direct dye in one bath.

The next table (3) shows the fastness properties of textiles that have been both scoured and dyed in the same bath, using eco-friendly scouring at different concentrations and dyeing concentrations.

Table (3): Fastness properties of the samples scoured and dyed samples in one bath.

Dye Conc.	Eco. Scouring Conc.	Washing Fastness		Fastness to alkaline perspiration			Fastness to Acidic Perspiration		
		Alt	St.	St. Cotton	St. Polyester	Alt.	St. Cotton	St. Polyester	Alt.
1%	1%	4	3/4	4/5	4	4	4/5	4	4
	2%	4	3/4	4/5	4	4	4/5	4	4
	3%	4/5	4	4/5	4/5	4/5	4/5	4/5	4/5

2%	1%	4	3/4	4/5	4	4	4/5	4	4
	2%	4	3/4	4/5	4	4	4/5	4	4
	3%	4/5	4	4/5	4	4	4/5	4	4
3%	1%	4	3/4	4/5	4	4	4/5	4	4
	2%	4	4	4/5	4	4	4/5	4	4
	3%	4	4	4/5	4	4	4/5	4	4

Alt= Alteration, St= Staining. The rating on the grey scale (5 means no alteration or staining on the white adjacent fabric; 1 means high alteration and staining)

The results from washing and perspiration fastness tests indicate that higher scouring concentrations (3%) generally lead to improved fastness properties, especially when used with lower dye concentrations. For washing fastness, the alteration ratings consistently improve with higher scouring concentrations, particularly at dye concentrations of 1% and 2%. Additionally, staining improves at a 3% scouring concentration. In terms of perspiration fastness, staining on cotton remains high (4/5) across all conditions, while polyester demonstrates improved fastness with higher scouring concentrations. Both alkaline and acidic perspiration fastness ratings also show improvement with higher scouring concentrations, indicating better resistance, particularly at lower dye concentrations. Using higher scouring concentrations enhances fastness properties, particularly in terms of staining and perspiration resistance.

In summary, the improvement in fastness properties with higher scouring concentrations may involve different factors. These include enhanced fiber preparation, better dye bonding, reduced damage to the fabric, and improved resistance to environmental factors. All of these contribute to improved performance in both washing and perspiration fastness tests.

3-4 Effect of scouring type and dye on tensile strength.

Figures (3-4) showed the maximum tensile force (N) for textile samples that have been subjected to different scouring and dyeing treatments, including both conventional and eco-friendly scouring methods. The results show that eco-friendly scouring methods result in higher tensile strength compared to conventional scouring, with maximum forces ranging from 561 N to 665 N, versus 552 N for conventional scouring, with the best results seen when scouring and dyeing are done together in the same bath.

This combined process enhances dye penetration and fiber strength, particularly at 3% dye concentration and 1% scouring concentration. eco-friendly scouring, especially when paired with simultaneous dyeing, significantly boosts fabric tensile strength and improves its durability.

When comparing eco-friendly scouring to conventional scouring, it is observed that eco-friendly scouring typically yields higher tensile strength across all dye concentrations. The maximum tensile force achieved with eco-friendly scouring ranges from 561 N to 665 N, whereas conventional scouring reaches a maximum of 552 N.

Regarding the impact of dye concentration, increasing the dye concentration generally enhances tensile strength. The most significant improvements occur when scouring and dyeing are performed together in the same bath. The highest tensile strengths are achieved with eco-friendly scouring when combined with dyeing in the same bath, especially at a 3% dye concentration and 1% scouring concentration.

In summary, the combination of eco-friendly scouring and simultaneous dyeing in the same bath results in the highest maximum tensile forces, indicating improved mechanical properties of the textile. This highlights that both the scouring method and the integrated process of scouring and dyeing contribute positively to the strength of the fabric.

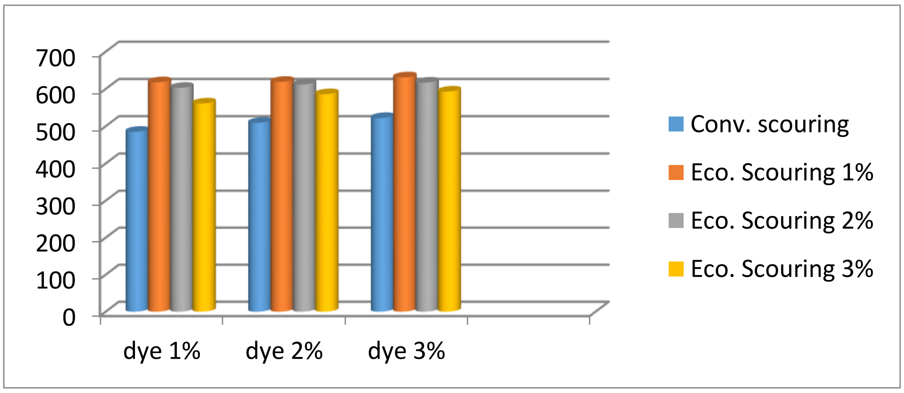

Figure (4) : Effect of scouring type and dyeing on Tensile strength

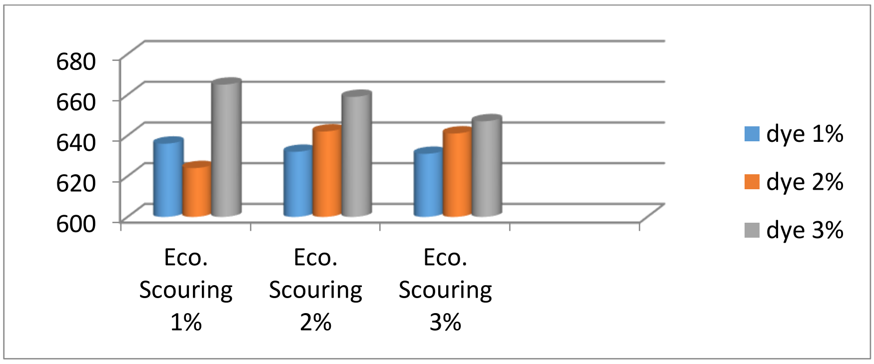

Figure (5) : Effect of eco scouring and dyeing(in the same bath) on Tensile strength

Conclusion

Eco-friendly scouring techniques have numerous benefits compared to traditional scouring in textile processing, especially when scouring and dyeing occur in a single bath. Textiles treated with environmentally friendly scouring chemicals regularly demonstrate elevated K/S values, signifying enhanced dye absorption and more vivid coloration irrespective of dye concentration. The fastness features, including washing and perspiration fastness, are often preserved or enhanced by eco-friendly scouring. Elevated dye concentrations enhance sweat resistance but may somewhat diminish washing fastness regarding color change. Eco-friendly scouring demonstrates performance in fastness qualities that is comparable to or superior to conventional scouring, especially for polyester materials and across diverse sweat circumstances. Eco-friendly scouring results in superior tensile strength at all dye concentrations compared to traditional procedures. The maximum tensile strengths are attained when scouring and dyeing occur simultaneously in the same solution, especially with elevated concentrations of dye and scouring agents. The integration of eco-friendly scouring with concurrent dyeing in a single bath not only amplifies color intensity and fastness but also boosts the mechanical strength of textiles. This renders it a superior alternative to traditional scouring techniques, enhancing both the quality and longevity of dyed textiles while remaining environmentally sustainable.

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