Optimizing Color Stripping Techniques for Quality Retention in Reactive Dyed Cotton Fabrics

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I. Introduction

The textile industry has faced increasing demand for high-quality fabrics, where dyeing faults such as overdyeing, off-shade, or uneven coloration have posed major challenges. Instead of discarding defective fabrics, color stripping has been recognized as a sustainable and cost-effective solution, enabling reuse without compromising quality. However, reactive dyes applied on cotton have formed strong covalent bonds with cellulose, making dye removal particularly difficult. Conventional reductive stripping using sodium hydrosulfite has been effective but has caused fabric damage and produced environmentally harmful effluents. Therefore, this study has explored an alternative chemical to replace sodium hydrosulfite, focusing on stripping efficiency, fabric quality retention, and environmental safety to identify a more sustainable solution.

II. Literature review

A. *Color Stripping in Textile*

Color stripping is a critical technique in textile manufacturing used to remove unwanted dye from fabrics, especially when faults like over-dyeing, uneven dyeing, color patching, and crease marks occur due to uncontrolled dyeing conditions or poor pre-treatment [1],[2],[3],[4]. Instead of discarding faulty batches, stripping offers a sustainable and cost-effective solution by reducing waste and resource usage [5].

B. *Stripping Mechanisms by Fabric Type*

Nylon dyed with acid dyes forming ionic bonds between dye sulfonate groups and nylon ammonium ions [6]. Stripping uses Formosul and formic acid to reduce dye molecules and maintain acidic conditions for effective removal [7]. Polyester dyed with disperse dyes via physical diffusion and held by Van der Waals forces [8],[9]. Stripping involves reduction (e.g., sodium formaldehyde sulfoxylate) and oxidation (e.g., sodium chlorite) to break chromophores and remove dye [10],[11]. Cotton dyed with reactive dyes forming covalent bonds with cellulose hydroxyl groups [12]. Stripping uses sodium hydrosulfite to reduce dye to a soluble leuco form, assisted by caustic soda, which risks cellulose degradation under high pH [5],[3].

C. *Cotton Color Stripping*

1) *Challenges in Cotton Color Stripping*

Cotton's cellulose structure is highly sensitive to alkaline and acidic conditions, leading to fiber damage and excessive swelling during stripping [13]. Compared to nylon and polyester, cotton is more vulnerable to chemical and thermal degradation [14].

2) *Cotton Color Stripping Methods*

Reductive: Uses reducing agents like sodium hydrosulfite, effective but environmentally harmful [5],[15].
Oxidative: Employs ozone and hydroxyl radicals; eco-friendly but less efficient at high dye concentrations [16].
Photo-Catalytic: Uses UV light and TiO_2 catalysts to generate reactive species for dye breakdown under mild conditions [17].
Biological: Utilizes microbes or enzymes; eco-friendly but slow and condition sensitive [18].

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3) Conventional Method – Sodium Hydrosulfite

Sodium hydrosulfite and caustic soda are used under high temperature and alkaline conditions to break dye chromophores [19]. While effective, this method causes strength, weight, and pilling resistance loss, and increases absorbency [5],[1]. It also generates harmful wastewater pollutants [2].

4) Alternative Method – Potassium Persulfate

Sodium Hydroxy methane Sulfinate: Effective for red dyes but less eco-friendly [2].
Thiourea Dioxide: More stable and efficient, but costly [2].
Potassium Persulfate: Oxidizes dye chromophores with fewer pollutants and minimal cellulose damage, offering a sustainable alternative [20].

Potassium persulfate ($K_2S_2O_8$) is a more sustainable alternative to sodium hydrosulfite for color stripping, acting as an oxidizing agent that effectively breaks down dye structures, especially in reactive dyes [21]. Unlike hydrosulfite, it causes less damage to cellulose fibers and generates fewer pollutants, resulting in lower COD and BOD levels in wastewater [20]. Its comparable cost and reduced environmental impact make it a viable and eco-friendly choice for industrial textile applications [2].

III. Materials and Methods

A. *Materials and Dyeing Process*

100% cotton bleached plain knitted fabric (28 Ne, 166 GSM) was dyed using Reactive Navy Blue F2GL (Reactive Blue 194), an azo-based dye. Supportive chemicals included Glauber's salt, soda ash, leveling agent, and soaping agent. Dyeing was performed in a lab machine (1:50 liquor ratio, 5 g samples) using a 5% color depth. The process involved controlled temperature increases, chemical additions, and post-dye washing. A total of 30 dye cycles were completed, and color depth was verified using K/S values.

B. *Conventional Color Stripping*

The Dyed fabrics were stripped using sodium hydrosulfite (10 g/L) and NaOH (10 g/L) at pH 12.2 and 80°C for 30 minutes. Post-stripping, fabrics were rinsed, dried, and conditioned. Wastewater samples were sent for COD and BOD analysis.

C. *Potassium Persulfate Stripping Trails*

Potassium persulfate was tested as an alternative stripping agent. Trials varied chemical concentrations (5–40 g/L), pH levels (10–12), and temperatures (80°C, 100°C), using NaOH and Na_2CO_3 as pH regulators. Based on initial results, 11 optimized recipes were tested using 10–20 g/L potassium persulfate, NaOH, pH 12, and 80°C. Final samples were evaluated and wastewater analyzed.

D. *Quality Evaluation*

Stripping effectiveness was measured via K/S values to calculate color removal percentage. Fabric properties were assessed through bursting strength loss (ISO 13938-1), weight loss, pilling resistance (ISO 12945-2:2020), and water absorbency (AATCC TM197-2011). COD and BOD tests followed APHA 5210B and 5220B methods.

IV. Results and Discussion

A. *Properties of Dyed Fabric*

Sample Analysis

Illum/Obs	DL*/ISL	Da*	Db*	DC*/cSC	DH*/SH	DEcmc	Decision
D65 10 Deg	0.04	-0.05	-0.01	0.01	-0.05	0.06	Pass
msTL84-10	0.04	-0.01	-0.01	0	-0.01	0.04	Pass
A 10 Deg	0.04	-0.05	-0.03	0.01	-0.04	0.06	Pass

Sample is: Decmc Tolerance: 1
Lighter (l/c) Ratio: (4.00 2.00)
more saturated
more green

Fig1. Dyed sample K/S value

TABLE I. DYED SAMPLE DATA

Parameter	Dyed Fabric
K/S value	6.5207
Bursting Strength	582.52 kPa
GSM	166.5
Pilling rating (5000 cycles)	5
Wicking weft	81mm
Wicking Warp	86mm

B. *Sodium Hydrosulfite Stripped Results*

TABLE II. SODIUM HYDROSULFITE STRIPPED SAMPLE DATA

Parameter	Dyed Fabric	Stripped Fabric
K/S value	6.5207	1.7528
Bursting Strength	582.52 kPa	531.52 kPa
GSM	166.5	158.94
Pilling rating (5000)	5	4
Wicking weft	81mm	98mm
Wicking Warp	86mm	107mm

- Stripping percentage - 73.12%
- Bursting strength loss - 8.76%
- Weight loss - 4.54%
- Absorbency for weft direction increases 20.99%
- Absorbency for warp direction increases 24.41%

C. *Potassium Persulfate Stripping Results*

TABLE III. POTASSIUM PERSULFATE STRIPPED SAMPLE DATA

Parameter	Conventional Stripped Fabric	Alternative Stripping Fabric
K/S value	1.7528	3.0852
Bursting Strength	531.52 kPa	541.33kPa
GSM	158.94	162.186
Pilling rating (5000)	4	4-5
Wicking weft	98mm	92mm
Wicking Warp	107mm	99mm

- Stripping percentage - 52.69%
- Bursting strength loss - 7.07%
- Weight loss - 2.59%
- Absorbency for the weft direction increases by 13.58%
- Absorbency for the warp direction increases by 15.12%

D. *BOD and COD Level results*

TABLE IV. COD & BOD LEVEL ANALYSIS

Parameter	Requirement	$Na_2S_2O_4$	$K_2S_2O_8$
BOD (mg/l)	Less than 75	960	59
COD (mg/l)	Less than 800	12000	451

E. *Discussion*

Potassium persulfate proves to be a promising and eco-friendly alternative to sodium hydrosulfite for color stripping of cotton fabrics. It offers better fabric preservation, with lower losses in bursting strength and weight, and improved pilling resistance. Environmentally, it is far superior, producing wastewater with BOD and COD levels well within marine discharge limits. Although its stripping efficiency is slightly lower, the overall balance of fabric quality and sustainability makes potassium persulfate a highly suitable choice for responsible textile processing. Moreover, the achieved stripping percentage is acceptable for practical use, as the process aims to reduce color depth rather than fully remove it, ensuring readiness for subsequent treatments.

V. CONCLUSION

This study confirms that potassium persulfate is a viable and eco-friendly alternative to sodium hydrosulfite for stripping reactive dyed cotton fabrics. Although it showed slightly lower dye removal efficiency, the level of color reduction achieved is sufficient for practical processing, as the goal is to lighten the shade rather than completely remove the dye. It caused less damage to fabric structure, resulting in better bursting strength, reduced weight loss, and improved pilling resistance. Water absorbency tests also indicated less fiber disruption. Most importantly, potassium persulfate produced significantly clean wastewater, with BOD and COD levels within acceptable limits. Overall, it offers a more sustainable solution that balances performance, fabric quality, and environmental responsibility, making it a practical choice for future textile processing.

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