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Posted Date: 16 May 2025

doi: 10.20944/preprints202505.1293.v1

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Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2025 doi:10.20944/preprints202505.1293.v1

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Impact of Sustainable Finishing Techniques on Textiles for Imparting Value Addition

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Abstract: The textile sector is experiencing revolutionary change towards sustainability, resulting from environmental concerns and the desire for eco-friendly products by consumers. Sustainable finishing techniques better textile functionality without doing a lot of damage to the environment, proving to add value in regards to superior performance, durability, and market appeal. Six important finishing methods for achieving sustainability are discussed in this article, which include anti-microbial finishes using natural ingredients, plasma treatment technology, nanotechnology, bioprocessing using enzymes, ultraviolet (UV) radiation technology, and ultrasound-based finishing. Each of the techniques is appraised in terms of value addition, environmental impact, and feasibility in the textile industry in the text.

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1. Introduction

Textile finishing improves the aesthetic, functional, and performance features of textiles, namely: softness, water retardance, and anti-microbial effects. Old-fashioned finishing procedures tend to depend upon the usage of cruel chemicals, high consumption of energy, and water-based processes, degrading the environment. Sustainable finishing methods overcome these issues by conserving the consumption of resources, minimizing wastage, and utilizing environmentally friendly materials. Not only do these techniques enhance the environmental impact of textiles, but they also enhance value by satisfying consumers' needs to embrace sustainable and high-performance products. This article explores the effect of six sustainable finishing methods on value addition in textiles, with the mechanism, benefits, and applications in mind.

2. Findings:

2.1. Anti-Microbial Finish Using Natural Ingredients

Mechanism and Materials: Anti-microbial finishes are used to avoid the growth of bacteria, fungi, and other microorganisms, making clothes more hygienic and durable. Natural anti-microbial by-products from plants, herbs, and other bio-based sources provide a viable alternative to synthetic little chemicals such as triclosan. Common natural ingredients include:

Neem (Azadirachta indica): Includes azadirachtin that damages the microbial cell walls.

Turmeric (Curcuma longa): Curcumin is antibacterial and antifungal thereby.

Chitosan: A biopolymer from crustacean shells, with a wide spectrum of antibacterial activity.

Essential oils: Tea tree, eucalyptus, and lavender oils have natural antimicrobial properties.

Such agents are administered by padding, coating, or microencapsulation, and the impact is prolonged without affecting the fabric's breathability.

Value Addition: Natural anti-microbial finishes empower textile function by:

- Improving hygiene: Excellent for medical textiles, sportswear, and home furnishings.
- Extending product life: Reduced microbial degradation enhances durability.

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- Meeting consumer preferences: Eco-conscious consumers prefer natural and chemical-free products.

Environmental Benefits: Natural ingredients do not pollute the environment as they are biodegradable, and they are also non-toxic and do not require much energy when applied. For instance, heavy metal-based chemicals are decreased with chitosan-based finishes, and hence, water pollution is reduced.

Challenges: Difficulties are reduced wash durability and increased expenses as compared to synthetic substitutes. The technology related to microencapsulation, as well as the cross-linking agents, is solving these problems and making natural anti-microbial finishes more viable.

2.2. Plasma Treatment Technology

Mechanism and Applications

Plasma treatment is a process whereby textiles are passed through an ionized gas (plasma), thereby altering surface properties but not the bulk properties. The plasma can be utilized in natural (cotton, wool), as well as man-made fibers (polyester, nylon), and mixed ones. Types of plasma treatments include:

Low-pressure plasma: Applied to accurate surface manipulation, such as hydrophilicity or hydrophobicity.

Atmospheric plasma: Suited for continuous flow process that saves energy costs.

Plasma treatments also make surfaces of textiles functional, allowing to introduction of chemical groups (hydroxyl, carboxyl) on surfaces or depositing thin layers, improving such properties as dyeability, adhesiveness, and water-repellency.

Value Addition: Plasma treatments add value by:

- Enhancing functionality: Better wettability for dyeing or waterproof linings for outside clothes.
- Increasing durability: Arising modifications enhance fiber bonds, thereby decreasing wear.
- Enabling customization: Customized finishes for particular applications, e.g., e.g., flame-retardant workwear.

Environmental Benefits: The plasma technology is eco-friendly because it does the following: The plasma technology stops the requirement of water and water-intensive wet processes. **It** consumes less energy than the traditional thermal treatment. Creates a negligible amount of waste since plasma reactions take place within a controlled setting.

Challenges: The High first cost of equipment and the requirement of special expertise are the restraining factors. Currently, ongoing research is reducing costs, thus making the treatments with plasma more available.

2.3. Nanotechnology

Mechanism and Implementation

Nanotechnology is the use of nanoparticles or nanostructured surface treatment of textiles with properties such as anti-microbial effects, UV protection, or self-cleaning. Nanotechnology that is sustainable takes interest in bio-based or non-toxic nanomaterials, including:

Silver nanoparticles (AgNPs): Offer anti-microbial properties but need proper control in order to prevent their environmental release.

Titanium dioxide (TiO2): Enables photocatalyst self-cleaning under UV light.

Cellulose nanofibers: Increase strength and breathability with renewable resource.

Nanoparticles are applied by padding, sprays, or sol-gel applications in such a way that ensures an even distribution.

Value Addition: Nanotechnology enhances textiles by:

- Improving performance: Self-cleaning fabrics reduce maintenance costs.

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- Adding premium features: UV-protective clothing has a health-conscious audience.
- Enabling innovation: Smart textiles containing nanosensors for medical uses.

Environmental Benefits: Eco-friendly nanotechnology diminishes the impact on the environment in the following ways:

Minimizing chemical use: Nanocoatings replace bulk chemical treatments.

Enhancing durability: Longer-lasting textiles reduce replacement frequency.

Using bio-based nanomaterials: Cellulose-based nanoparticles are biodegradable.

Challenges: The environmental fate of synthetic nanoparticles, like silver, raises concerns about toxicity. Scaling up of the bio-based nanomaterials and their compliance with regulations is key to sustainable bioapplication.

2.4. Bioprocessing Using Enzymes

Mechanism and Applications

With the help of biocatalysts, enzyme-based bioprocessing manipulates textile surfaces, eliminating harsh chemicals in desizing, scouring, or bleaching. Common enzymes include:

Amylases: Get rid of starch-based sizing agents in cotton.

Cellulases: Soften denim through bio-polishing.

Pectinases: Help in eco-friendly scouring of natural fibers.

Enzymes are used at mild conditions in aqueous solutions (pH 4- 8, 30 – 60 ◦ C) and thus save energy and decrease the amount of water used.

Value Addition: Enzyme treatments add value by:

- Enhancing aesthetics: Bio-polishing enhances the softness and look of the fabric.
- Improving comfort: Smoother surfaces enhance wearability.
- Supporting premium branding: The textiles that underwent enzymatic treatment are sold in the form of eco-friendly materials.

Environmental Benefits: Enzymes are biodegradable and they carry out their function under mild conditions, hence achieving the following:

Reduced energy consumption: Lower processing temperatures in comparison with chemical processes.

Decreased water use: Reduced rinses from little chemical residues.

Lower chemical waste: Enzymes are used as substitutes for poisonous agents such as sodium hydroxide.

Challenges: The enzyme specificity restricts the use to some fibers, and the cost can be a hindrance to their use. The progress in the field of enzyme engineering is increasing its utility and affordability.

2.5. Ultraviolet Radiation Technology

Mechanism and Applications

UV radiation technology is based on UV light (200–400 nm) used for textile surfaces functionalization under the conditions of UV radiation, sometimes in combination with photon sensitizers or photocatalysts like TiO2. UV treatments alter surface chemistry, augmenting such advantages as hydrophilicity or anti-microbial effect. Applications include:

UV curing: Polymerizes coatings for waterproofing or for fire retardant finishes.

Surface activation: Enhances dye uptake by artificial fibres.

Value Addition: UV technology adds value by:

- Enhancing functionality: Anti-microbial or UV-defense for outdoor clothing.
- Improving efficiency: Rapid curing reduces processing time.
- Enabling niche applications: Medical textiles treated by UV with improved hygiene.

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Environmental Benefits: The following are the reasons that make UV treatments sustainable:
Low energy use: Compared to thermal processes, UV lamps do not use much power.
Minimal chemical use: Photocatalytic reactions do not make direct use of poisonous agents.
No wastewater: Dry processing eliminates effluent discharge.
Challenges: Restricted penetration depth allows UV applications to surface modifications only, and powerful UV systems can only be used with due care for the workers' safety.

2.6. Ultrasound-Based Finishing

Mechanism and Applications

Using ultrasound for finishing implies application of high-frequency sound waves (20 kHz-100MHz) in improving textile processing. Cavitation bubbles get incorporated by the ultrasonic waves into liquids, enhancing the penetration of finishing agents into the fibers. Applications include:
Dyeing and finishing: Ultrasound increases the adsorption of dyes and functional layers.
Cleaning: Removes impurities without harsh chemicals.
Value Addition: Ultrasound treatments add value by:

- Improving efficiency: Faster processing reduces production costs.
- Enhancing quality: Even coating distribution increases finishing consistency.
- Supporting innovation: Ability to allow green finishes to high-performance textiles.

Environmental Benefits: Ultrasound technology is environmentally-friendly because it;
Reduces chemical use: Improved penetration reduces the need for the agents in excess.
Decreases energy consumption: Reduced processing times as compared to traditional ones.
Minimizes water use: Fast agent uptake decreases the rinse needs.
Challenges: Scaling the ultrasonic systems for industrial applications is difficult; the high cost of equipment and low tolerance for control to prevent fiber breakage are the reasons.

3. Comparative Analysis

Technique	**Value Addition**	**Environmental Benefits**	**Challenges**
Natural Anti-Microbial	Hygiene, durability	Biodegradable, low toxicity	Wash durability, cost
Plasma Treatment	Functionality, customization	Waterless, low waste	Equipment cost
Nanotechnology	Performance, innovation	Reduced chemical use	Nanoparticle toxicity
Enzyme Bioprocessing	Aesthetics, comfort	Low energy, biodegradable	Enzyme specificity
UV Radiation	Functionality, efficiency	Low energy, no wastewater	Limited penetration

Ultrasound	Efficiency, quality	Reduced chemical use	Scaling issues

Each technique has its advantages, and the ones to be used depend on the type of fiber, application, and cost comparisons.

4. Case Studies

Chitosan-Based Medical Textiles: A European manufacturer used chitosan finishes for surgical gowns to reach 99% bacterial reduction and chemical waste reduction by 30%.

Plasma-Treated Polyester: In sportswear, a brand has used atmospheric plasma to improve water repellency and thereby cut water consumption of finishing by half and increase the sustainability of products.

Enzyme-Treated Denim: A major denim manufacturer embraced cellulase bio-polishing, which saved up to 20% in electricity bills and made fabric softer, increasing market share.

5. Future Prospects

The future of sustainable textile finishing is in the hybrid approach in order to achieve synergistic effects, such as plasma and nanotechnology. Progress in bio-based nanomaterials and enzyme engineering will continue to bring down the costs and increase the scope of application. Industry uptake will be increased by the supportive policies and consumer awareness, assuming that the eco-friendly textile innovation will be stimulated.

6. Conclusion

Sustainable finishing techniques such as natural anti-microbial finishes, plasma treatments, nanotechnology, enzyme bioprocessing, UV radiation, and ultrasound-based finishing have great value-added properties to textiles. These methods enable the products to be more functional, durable, and marketable, which respond to supply demands for high-performance and eco-friendly items. Their environmental advantages, such as less consumption of resources and waste, are in tandem with the global sustainability efforts. Spurred by numerous challenges of cost and scalability, continuous research and industry acceptance are clearing the path for a greener future of textile.

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