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Sustainable textile finishes: A boon for reducing toxic disposal to the environment

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Abstract
An eco-friendly strategy is being implemented in all fields, including textiles due to the current surge in environmental concerns. Changes in textile finishing processes have been implemented in order to follow this strategy, resulting in a minimum loss of natural resources and reduced hazardous waste. Fierce competition and rising globalization have created a huge challenge for textile researchers and manufacturers in the development of green functional textiles. The increasing expansion of technical textiles and their applications has created several opportunities for the use of innovative finishes. The Indian textile sector consumes 200–300 m^3 of water for every ton of treated textiles, resulting in massive wastewater production. Traditional textile pre-treatment procedures such as desizing, scouring, and bleaching need large amount of chemicals as well as water, of them unexhausted chemicals are drained into the effluent stream. Enzymatic desizing, solvent desizing, ultrasonic treatment, and plasma treatment are a few environmentally acceptable ways for desizing textile materials. Enzymes such as pectinase, arylesterase, xylanases, cellulases, laccases, and ligninases are used in bioscouring or enzymatic scouring to remove the impurities from textile fabrics. Ultrasound technology decreases water and detergent usage while also shortening scouring time. Lipase, lactase, and cellulase enzymes are utilised in the bio bleaching process. There are other eco-friendly finishing processes utilising nanotechnology and microencapsulation, such as biosingeing, biopolishing, and antimicrobial finishes. The major goal of applying new technologies and ideas to textile finishes is to decrease the detrimental impact of chemicals used in traditional textile finishing processes on human health and the environment. Specialty chemicals and laser technologies have proven to be a boon for lowering pollutant load in an environmentally acceptable and sustainable manner.

Keywords: environment, pollution, sustainability, enzymes, plasma and ultrasonic treatment

1. Introduction

Important legislation on eco-toxicological issues has been adopted in recent years, as public awareness on environmental problems has grown. The term, ‘Eco-friendly’ is used to refer to the goods and services that are considered to cause little or no harm to the environment. 'Think globally, act locally' is the slogan of the future for the global textiles business [10]. It is linked to a number of significant concerns, including health and safety during chemical storage, application, and usage, as well as proper disposal of chemicals into landfills and water, and emission into the air during textile chemical processing. Chemical coatings and finishing processes have to adapt as a result of this. As a result, in this new millennium, comprehensive pollution management is required for the development of environmentally friendly processes. The economy and environment have been driving forces in modern technology, and finishers are attempting to make textiles more effectively, with less water and pollutants. Emerging trends with sustainable concepts where natural materials, plant components, and plant extracts may be utilised for textile finishing are rooted in environmental concern, pollution control, and user-friendliness [34]. Fabrics that had not been treated, commonly known as grey fabric, were desized, scoured, and bleached separately in separate tubs. The rise of industry and urbanisation exacerbates the problem of rising water consumption. According to a poll performed by the FICCI Water Mission, industrial water consumption is expected to grow to 8.5 and 10.1 percent of total freshwater outflow in 2025 and 2050, respectively [1]. The Indian textile industry now uses 200–300 m^3 of water per ton of the processed textiles also generating a huge amount of wastewater [9, 40]. This article provides an overview of the different environmentally friendly pretreatments for finishing textile fabrics. Developments in plasma treatment, antibacterial/antimicrobial, fragrance and UV-protective finishes have also been highlighted.

2. Pretreatment of Textiles For Finishing

Pre-treatment of textiles includes singeing, desizing, scouring, and bleaching. Each operation necessitates a large number of chemicals as well as water, with the unexhausted chemicals being drained into the effluent stream. Desizing, scouring, and bleaching are the three steps in the traditional pre-treatment procedure. Desizing a grey cloth involves utilising water (rot steeping), acid, enzyme, oxidation chemicals, and alkali to remove previously added size or starchy substance. To enhance absorbency, scouring utilises alkali to remove oils, fats, and waxes, whereas bleaching uses oxidising chemicals to improve the whiteness of the cloth. In a traditional procedure, scouring and bleaching are done just once, resulting in alkali and hydrogen peroxide being underutilized [14].

2.1 Bio-Singeing or Bio-polishing: It is a fabric finishing technique that improves fabric quality by reducing pilling and fuzziness in textiles. Hydrolases (Cellulases) enzyme is used to eliminate microfibrils from cellulosic fibres. It can be done in both batch-wise and continuous processes. Following are the primary features imparted to the cloth after bio-polishing treatment:

- A cleaner surface is obtained, resulting in a cooler sensation.
- As a secondary effect, lustre is produced.
- The fabric becomes softer.
- Tendency of the fabric towards pilling ends [26].

To enhance the softness of a cotton/jute blended fabric, cellulases, xylanase, and pectinase enzymes were employed. This enzyme removes projecting fibres from the fabric's surface, and the reducing sugar produced by these enzymes softens the cloth [45].

2.2 Desizing: It is the procedure for removing sizing ingredients such as starch or PVA from textile fabrics. Traditionally, desizing was done in hot water using oxidative and acid desizing chemicals [44]. The following are some environmentally acceptable ways for desizing textile materials:

2.1.1 Enzymatic desizing: Amanuel, L and Teferi, X used Aloe gel to desize cotton fabric. Amylase, liaise, catalase, lipase, cellulose, alkaline phosphatase, and carboxypeptidase are enzymes found in aloe vera, a medicinal plant. Calcium, sodium, copper, magnesium, zinc, chromium, manganese, and iron are all minerals found in aloe vera. Minerals such as manganese are important components of enzymes that aid in the activation of enzymes found in aloe vera gel. Enzymatic cotton desizing was performed at 70-80 °C for 60 minutes using 50-60 g/L aloe gel and 5 g/L sodium chlorite. When aloe gel desizing was compared to synthetic enzyme desizing, aloe gel desizing resulted in a significant weight reduction, proving that desizing with aloe gel is more efficient than synthetic enzyme desizing. The antiseptic components like sulphates, anthraquinones, and salicylic acid of aloe vera gel also provide an antibacterial finish to the cotton fabric [2].

2.1.2 Solvent desizing: It's a highly clean process with no waste disposal issues and pollution is minimal. The time it takes to desize and the amount of space machinery takes up on the floor is considerably less than with traditional methods. The size removal is more consistent due to the rapid and even solvent penetration. The solvents are recovered and produce little or no waste. This technique is advantageous since it consumes less energy and time to desize. Without felting, acrylic and wool textiles gain a glossy, silky touch in solvent. The caustic scouring step is skipped when solvent desizing is followed by bleaching [14].

2.1.3 Ultrasonic desizing: Frequency is the most important component in this process since it is utilised as an energy source for running equipment and speeding up chemical processes in solid, liquid, and gaseous media. Ultrasonic textile treatments use frequencies of more than 20,000 MHz (beyond human hearing). This ultrasonic energy is utilised in textiles processing for removing the size material to increase the efficiency and evenness of dye or finish dispersion into the fibre. This approach is also used in other textile processes such as enzymatic bioprocessing of cotton and scouring of wool. Ultrasonic energy, according to experts, may be used in textile cleaning [36].

2.1.4 Plasma desizing: The technique of plasma processing on sized textiles entails an 8-10 minute exposure to 100-200w oxygen plasma. This method includes converting organic-sized elements straight into gaseous phase without the need of liquids, resulting in direct evacuation. After that, a water rinse is required to remove around 30-35 percent of the remaining sizing material. The drawback of this technique is that sized material that would normally be collected in a traditional procedure could not be retrieved [38]. Atmospheric pressure plasma was used for cotton fabric desizing, scouring, and bleaching. Plasma treated cotton fabrics have a greater wettability than traditionally treated cotton fabrics, according to the findings [20].

2.2 Bioscouring or Enzymatic scouring: It is a method of removing impurities from textile materials using enzymes such as cellulases, pectinase, xylanases, arylesterase, ligninases and laccases. Enzymes are the bioactive catalysts that may be easily extracted from juice production waste and plant tissues. Various chemicals, such as sodium hydroxide and sodium bicarbonate, are employed in the scouring process, which adds to the pollution burden. The employment of enzymes aids in the removal of such hazardous compounds, lowering pollution levels. Alpaca wool was scoured with ultrasonic technique which reduced water and detergents consumption and shortened the time of scouring, most importantly the obtained scoured wool was without damages and entanglements [7]. Compared to traditional scouring, the bioscouring method causes relatively little strength loss in cotton fabric. As a result, this approach offers decreased strength loss, no chemical use, energy savings, time savings, and lower effluent treatment costs, making bioscouring favourable from a quality, environmental, and economic standpoint [48]. For bioscouring cotton fabric, a pectinase enzyme produced from the *Paecilomyces variotii* fungus was utilised. Pectinase enzymes are frequently employed in the beverage industry for wine clarity, juice clarification, and tea or coffee fermentation. Wastewater treatment, paper bleaching, vegetable oil extraction, and poultry feed additives are among the other applications [36].

2.3 Bleaching: Nowadays, enzymes such as glucose oxidase, laccase, and proteases are used to bleach textile fabrics. To bleach indigo colour and give denim a "wash down appearance," bio bleaching is commonly used on denim fabrics. Lipase and lactase are two enzymes commonly utilised in denim bio bleaching. The cellulase enzyme was also employed to give denim textiles a "salt and pepper" appearance. Enzymatically-generated hydrogen peroxide (H_2O_2) using glucose oxidase (GOX) is a sustainable alternative for cotton textile bleaching. GOX catalyzes the oxidation of glucose to gluconic acid with generation of H_2O_2 as a side product for bleaching. Cotton fabric bleaching with enzymatically-generated H_2O_2 was studied. Enzyme and glucose concentrations significantly affect peroxide generation as well as bleaching and were optimized using statistical experimental design in reference to maximum whiteness. Furthermore, the sustainability of this bleaching system was premeditated by GOX immobilization. GOX was covalently immobilized onto a natural and inexpensive support (chitosan) based on statistical experimental design results. The immobilization improved whitening results as well as allowing repeated application of enzymes for H_2O_2 generation, which was successively implemented for cotton textile bleaching [28].

2.3.1 Ozone Assisted Textile Bleaching: Ozone is a gas which is characterized by its blue color. The chemical formula of ozone is O3 i.e. trioxygen. It is widely used in textile wet processing for bleaching of textile materials. Although ozone was first used as a bleaching agent in the paper industry, it has now been used as a bleaching agent for different types of fibres such as cotton, jute, nylon and silk. Ozone can be converted back to oxygen because it is thermodynamically unstable. Another use of ozone in the textile field is in wastewater treatment of textile dye effluent. According to Guendy, ozone is a strong oxidizing agent and is capable of removing colour completely from effluent [16].

Eren and Öztürk investigated ozonation of cotton fabrics. The results showed that the starch size removal of the greige cotton samples and the water absorbency of the greige and desized cotton samples are increased by ozonation. But ozonation does not remove the motes successfully. Bleaching effect of ozonation is successful because of the high oxidation potential of ozone [12].

Starch sized 100% cotton woven fabrics need desizing, scouring and bleaching treatments prior to coloration and finishing. Traditionally, alpha-amylase-based enzymatic desizing and combined scouring and bleaching with an alkali, surfactant and H_2O_2 are used. Constant research is conducted on combining the desizing, scouring and bleaching processes into a single step by many researchers. Enzymatic desizing and alkaline H_2O_2 scouring and bleaching with a surfactant and stabilizer were combined. The treatment resulted in efficient desizing, scouring and bleaching, leading to excellent size removal, absorbency, seed/mote removal and whiteness index levels, and comparable tensile and tear strength levels to that of the two-step process. The dyeability aspects were comparable in terms of surface color strength (K/S), color difference (ΔE) and fastness ratings. Around 50–75% savings in water, energy, power, time and effluent generation were reported. The chemical oxygen demand, biological oxygen demand, total dissolved solids, pH and turbidity values of the resulting effluent were found to be remarkably lower. The technology was also tested industrially and found to be successful [50].

2.5 Degumming: The process of removal of sericin layer prior to dyeing/printing or finishing, in order toachieve bright/lustrous fabric. Conventional process of degumming involves alkaline soaping at pH 10-11 and 90-95 ºC for 1 hour. In a study conducted by Tong *et al.* a bacterial strain *Pectobacterium carotovorum* HG-49, was isolated and successfully applied to the degumming of ramie fibers. After degumming, the residual gum content of ramie fibers decreased to 1.85%, which exceeded the first-class standards of China textile criteria. This eco friendly method did not use acid and highly reduced alkali consumption [49].

Mengxiong *et al.* in their research on eco friendly degumming process of flax roving, utilized *Bacillus subtilis* HR5 to achieve degumming effect. Outcome of environmental scanning electron microscopy, Fourier-transform infrared spectroscopy, thermogravimetric analysis and X-ray diffractometry analyses showed that the gum was remarkably reduced and overall quality i.e. the breaking tenacity and antibacterial activity of fibers degummed by microbial treatment were better than those treated with traditional degumming [29].

In a study performed by Biswas *et al.* degumming of ramie with a new enzyme formulation i.e. pectinolytic and hemi cellulolytic enzymes (pectinase, hemicellulase) was investigated and the process was optimized considering weight loss, tensile properties of degummed fiber and economic processing. A residual gum content of 5.36% was achieved at comparatively lower enzyme concentration under ambient temperatures (28–35°C) in 24 hours. On examining the electronic microscopic pictures, the appearance and aesthetics of eco-degummed ramie fiber have been found to have improved significantly [6].

2.6 Mercerization: A treatment specific to cotton, which improves its tensile strength, lusture and ability to take up dyes. Baths containing very concentrated solutions of sodium hydroxide (20- 30%) are used. Large volume of dilute caustic soda solution is produced in this process, which is a cause of water pollution. The study investigates the use of ultrasonic energy to provide a more efficient and eco-friendly mercerizing process. For both conventional and ultrasound-assisted techniques, the process variables, including sodium hydroxide concentration, reaction time, temperature, tensile strength and degree of mercerization, the study investigates the use of ultrasonic energy to provide a more efficient and eco-friendly mercerizing process. For both conventional and ultrasound-assisted techniques, the process variables, including sodium hydroxide concentration, reaction time, temperature, tensile strength and degree of mercerization [30].

Khajavi *et al.* investigated the use of ultrasonic energy for providing an efficient and eco-friendly mercerization process. It was revealed in the study that a higher tenacity and a lower alkali concentration were found in the mercerizing bath. Hence, it was concluded that ultrasound assisted mercerization may be an efficient and eco friendly alternative to the conventional process [23].

3. Finishing

The increase in the market competitiveness along with the diversity of consumers' demands has created a challenging environment in the textile sector. Therefore, the textile industry has shown a growing interest in the finishing of conventional fabrics to produce innovative products with durable functional properties such as aroma and antimicrobial that enhance health, safety and ergonomics by employing green chemistry materials and processes [42]. Finishes serve a significant purpose in the overall performance of the fibre, yarn and fabric. The worldwide competition and increasing globalization have created many challenges to textile researchers and industrialists for the production of green functional textiles. Buyers always expect a high degree of wearing comfort and finishing plays an important role in achieving it. The new developments in the specialty finishing sector are driven by consumers' changing lifestyle towards a more casual clothing look with greater performance. The rapid growth in technical textiles and their end-uses has generated many opportunities for the application of innovative finishes [21, 41].

Functional textiles are one of the novel products in the textile area. They are obtained by either incorporating active ingredients into conventional fabrics such as cotton, wool, silk or polyester or by manufacturing new materials like nanofibres and nanocomposites. Innovative technologies in textiles have succeeded in offering a wide variety of fabrics with unprecedented functions. The most common applications of functional textiles include phase change materials, insect repellents, antimicrobials, fragrances, dyes, colourants, skin softeners, moisturizers and flame retardants [35].

3.1 Anti-microbial finish: In recent years, new developments in functional and smart textiles took place. These textiles are capable of sensing changes in environmental conditions or body functions and responding to these changes. The attitude and demands of consumers towards hygiene and active lifestyle has created a wide range of textile products finished with antimicrobial properties, which in turn has stimulated intensive research and development. There is an endless resource of natural antimicrobial peptides which can be exploited for imparting antimicrobial properties to textile substrates [4].

3.1.1 Nanotechnology: It is the science of the small with big potential. It is one of the most rapidly emerging key technologies of the 21st century. In recent years, noble metal nanoparticles have been the subject of research due to their unique electronic, optical, mechanical, magnetic and chemical properties that are significantly different from those of bulk materials. Therefore, metallic nanoparticles have found use in many applications in various fields. Materials in the range of 1 nm- 100 nm hold much interest because it is in this range that a number of newer properties become effective. The most widely used example of textile finishes by nanotechnology is of antimicrobial finishing. Though the use of textile finishing agents have been known for decades, it is only in recent years that attempts have been made on finishing textiles with nano-particles as antibacterial compounds. Due to an increase in awareness about health and hygiene, people increasingly want their clothing to be hygienically fresh [11].

Many of the antimicrobial agents available in the market are synthetic based and may not be environmentally friendly. Due to this, many of the consumers are opting for herbal antimicrobial finishes for textiles. It must be ensured that these substances are not only permanently effective but also that they are compatible with skin and environment. Complex metallic compounds based on metals like copper, silver, zinc etc. cause inhibition of metabolism [22].

3.1.2 Microencapsulation: It is one of the novel methods of getting functional finishes on textiles. Microencapsulation is a micro-packaging technique involving deposition of thin polymeric coating on small particles of solid or liquid. This process is more advantageous to conventional process in terms of economy, energy-saving, eco-friendliness and controlled release of substances. The anti-bacterial agents reside in colloidal suspension with the amorphous zone of the polymeric binder so that a reservoir of agent is present in solid/ solution within the polymer matrix. The healing value of herbal-treated textile (or herbal garment) and its usage is based on the principle of touch. When the body comes in contact with the herbal cloth, it loses toxins and its metabolism is enhanced. These garments help in fighting many common and prevalent diseases such as hypertension, heart ailments, asthma, diabetes and skin diseases. For diabetes, *Mimosa pudica* (touch-me-not), cumon/cumin seeds, *Magnolia champaca* (champa flower) and *Hibiscus rosa-sinensis* or shoe flower are combined in the herbal dye. The main herbs used in the herbal dye for arthritis are curry leaves and apocynceae. Whereas, for skin diseases, the herbs used are turmeric, neem, indigo and sandalwood. *Rubia cordifola, majith* are known to be effective against diseases like leprosy. Katha, catechu is used for treatment of parasitic infestation and itching [43].

3.2 Fragrance finishing: Fragrance finishing of textile material increases the value of the product by adding beneficial factors and such factors affect moods of the wearer. The term aromatherapy was coined in late 1920s by French cosmetic chemist, Rene-Maurice Gattefosse. Aromatherapy derived its name from the word aroma which means fragrance or smell and therapy means treatment. It is the art and science of using naturally extracted aromatic plant essential oils to balance, calm, cure infections and promote the health of body, mind and soul [14]. Many ancient civilizations like Egypt, China and India have used this as a popular complementary and alternative therapy from atleast 6000 years. Aromatherapy has established itself for the treatment of various arrays of complications and conditions. This therapy has gained a lot of attention in the 20th century and is very popular in the 21st century too and due to its importance, popularity and widespread use, it is recognized as aroma science therapy [24, 13].

Table 1: Application of eco-friendly antimicrobial and aroma finish to textiles

Fabric	Finish/ properties	Material and method
Cotton	Antimicrobial and Aroma	Essential oils Extracted from green, black and orange lemon peel (Citrus limon) were used [52]
Cotton	Antimicrobial and Aroma	Jasmine oil was applied. Gas Chromatography Mass Spectrometry (GCMS) and Fourier Transform Infrared Spectroscopy (FTIR) analysis was also done to characterize the chemical groups in jasmine oil [8]
Silk	Ultraviolet Resistant and Aroma	Microcapsules of lemon and eucalyptus essential oils applied with acrylic binder [27]
Cotton and cotton/polyester blend	Aroma	Melamine-based microcapsules with sage/rose essential oil were applied through pad-dry-cure method using commercial acrylate-based binder [46]

Cotton	Antimicrobial and Aroma	Lemongrass essential oil microcapsules were developed using complex coacervation technique and applied on fabric by exhaust and pad-dry-cure methods [5]
Cotton	Aroma	Geranium oil microcapsules were applied using complex coacervation techniques through direct and pad-dry-cure method [25]
Cotton	More flexible and pliable fabrics	Vetiver root extract and vetiver oil microcapsules were applied using pad-dry-cure method [33]

3.3 UV protective finish: Ultraviolet radiations are one of the electromagnetic radiations emitted by the sun having wavelengths in between 100 to 400 mm. The growing understanding of the effects and consequences of UV radiation exposure on skin cancer has resulted in a rise in R&D focused on UV ray protection. It has become even more essential as a result of the stratospheric ozone layer depletion caused by the widespread use of CFCs as coolants. [31]**.** Human underlying tissues are protected from UV radiation by a specific treatment designed to protect the cloth from UV radiation known as UV protective finish [39]. Natural dyes have been widely documented for UV protective finishing of textile fabrics. Other natural herbal items that can be used for this purpose include aloe vera, tea tree oil, eucalyptus oil, and tulsi leaf (*Ocimum basilicum*) extracts [19].

Table 2: Application of eco-friendly UV- protective finish to textiles

S. No.	Reference	Fabric	Material used	Fabric Finishing Method	UPF protection Category
1.	[15]	Bamboo/Tencel (50:50)	Thyme oil Cypress oil Grapefruit oil	Microencapsulation	Good
2.	[47]	Cotton	Neem leaves	Nanoparticles and nanocomposite coating Pad-Dry-Cure	Excellent
3.	[3]	Cotton	Betel leaves Curry leaves Tea leaves	Exhaust	Excellent
4.	[17]	Cotton	Blackberry leaves	Pad-Dry-Cure	Excellent
5.	[51]	Cotton	Fresh Pomegranate rind HTHP Dyeing and Mordanting	Alum	Very Good
				Tartaric acid	Very Good
				Chitosan	Very Good
			Fresh green tea HTHP Dyeing and Mordanting	Alum	Excellent
				Tartaric acid	Excellent
				Chitosan	Excellent
6.	[37]	Nettle	Cutch Dyeing and Mordanting	Myrobalan	Excellent
				$FeSO_4$	Excellent
			Madder Dyeing and Mordanting	Myrobalan	Excellent
				$FeSO_4$	Excellent

4. Conclusion

Various textile finishing techniques have emerged in recent years as a result of breakthrough technologies. Chemical finishes, a subset of textile finishes, use a significant quantity of water and chemicals, resulting in water waste and increased pollution. The textile sector is a big contributor to pollution in the environment. As a result, it is every individual's moral responsibility to adopt technologies that promote environmental well-being, which in turn benefits living beings. This review paper's major focus is on how to lessen chemical effects utilising sustainable ways that not only preserve the environment but also improve the physical and chemical qualities of natural and synthetic fibres. There are several plant extracts with significant medicinal uses. To now, these extracts and herbs have only been taken orally or applied directly to the skin. However, the utilisation of these plant extracts in textiles has created a new way. Plasma finishing, enzymatic finishing, nanotechnology, and microencapsulation are all excellent methods for creating environmentally friendly finishes. Plasma technology has shown to be quite successful because it uses little energy and chemicals and has no waste disposal issues. Because enzymes are natural compounds, they are fully biodegradable and do not pollute the environment. In order to fulfill expanding market needs, the textile finishing sector's future vision is to integrate finishing procedures with the use of highly advanced value added techniques for textile finishes. As a result, it can be stated that the effective application of sophisticated technology expands the sector's potential and makes textile finishing easier and more efficient.

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