ПРИЛОЖЕНИЕ НА ПОВЪРХНОСТНО АКТИВНИ ВЕЩЕСТВА ПРИ ПРЕДВАРИТЕЛНАТА ОБРАБОТКА НА СУРОВИ ТЕКСТИЛНИ ПЛАТОВЕ

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APPLICATION OF SURFACTANTS IN THE PRETREATMENT OF RAW TEXTILE FABRICS

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Abstract:

The pretreatment of raw textile fabrics is a critical phase in textile processing, aimed at removing impurities and enhancing fabric wettability, absorbency, and dye affinity. Surfactants play a pivotal role in this stage by facilitating the efficient removal of natural and processing-related contaminants such as waxes, oils, pectins, and sizing agents. This study examines the application of various classes of surfactants – anionic, cationic, nonionic, and amphoteric – in the pretreatment of different textile substrates. The mechanisms of surfactant action, including emulsification, wetting, and detergency, are analyzed to evaluate their impact on process efficiency and fabric quality. Comparative assessments highlight the influence of surfactant type and concentration on parameters such as fabric whiteness, absorbency, and tensile strength. The research further discusses environmental implications and the potential of biodegradable surfactants as sustainable alternatives to conventional agents. Overall, the findings underscore the significance of optimizing surfactant selection and process conditions to achieve effective, eco-friendly textile pretreatment outcomes.

Keywords: surfactants, raw textile, application, processing, biosurfactants.

Introduction

Textiles represent essential elements of both industrial production and everyday life, encompassing a wide range of categories including apparel, industrial fabrics, and household products. Textile auxiliaries play a crucial role in enhancing textile quality, endowing fabrics with specific functional properties, extending their service life, and contributing to energy efficiency and emission reduction. At present, the field of textile auxiliaries includes approximately 100 distinct types, with nearly 16,000 different formulations [1].

Surfactants constitute indispensable components of the global chemical industry due to their remarkable versatility. Their primary characteristic lies in the ability to lower surface tension. Upon reaching an interface, surfactant molecules replace water molecules and disrupt the hydrogen bonds between them, thereby reducing surface tension. This decrease – from about 72 to 35 dyne/cm – facilitates the formation of emulsions and promotes the uniform spreading of liquids over surfaces [2].

Most synthetic surfactants, produced mainly from petrochemical sources, have long served as key ingredients in detergents, cosmetics, agrochemicals, and pharmaceuticals. However, despite their efficiency, these compounds present significant environmental and health concerns. Due to their limited biodegradability, many synthetic surfactants persist in aquatic ecosystems, where they may harm aquatic organisms and disturb microbial balance [2, 3].

Bio-based surfactants, commonly referred to as biosurfactants, have attracted growing scientific and industrial interest in recent years. Owing to their superior biodegradability, lower toxicity, and renewable origins, these compounds are in accordance with the principles of green chemistry. They are derived from renewable biological sources such as waste biomass, microbial fermentation processes, and plant-based oils. Moreover, numerous biosurfactants exhibit exceptional functional characteristics, including strong surface activity and high stability under demanding environmental conditions. The adoption of such eco-friendly surfactants enables industries to lessen their ecological footprint and foster the development of a low-impact, circular chemical economy [4].

Raw textile materials – such as cotton, wool, linen, and synthetic fibers – naturally contain impurities including waxes, oils, pectins, and residual processing agents. Prior to dyeing or finishing, these impurities must be removed through a process known as scouring or refining. In this context, surfactants are indispensable, as they reduce surface tension, emulsify oils, disperse particulate matter, and facilitate fiber wetting [5].

An effective surfactant for textile refinement should [6]:

• Retain its performance under high temperature, pressure, and strongly alkaline or acidic conditions typical of textile processing baths.

• Ensure stable emulsification in the presence of electrolytes, hardness ions, or organic contaminants.

• Exhibit resistance to degradation over multiple washing or processing cycles, thereby remaining suitable for multi-bath applications.

Commonly utilized persistent surfactants in textile finishing include [7]:

• Non-ionic surfactants such as ethoxylated alcohols and alkylphenol ethoxylates (the latter increasingly restricted due to environmental concerns);

• Amphoteric surfactants like betaines, which maintain stability across a wide pH range;

• Specialty polymeric surfactants capable of forming stable micelles even in high-salt or strongly alkaline media.

These surfactants are employed in several finishing operations, including [8]:

• Scouring, to remove natural oils and waxes while preventing their redeposition;

• Desizing, to promote uniform elimination of starch or synthetic sizing agents;

• Bleaching preparation, to enhance fiber wettability and ensure even oxidizer penetration;

• Mercerization assistance, to improve fiber swelling and facilitate alkali penetration.

However, conventional surfactants are often poorly biodegradable, presenting challenges in wastewater treatment and environmental management. Consequently, contemporary textile chemistry increasingly emphasizes the use of biodegradable surfactants – such as sugar-based alkyl polyglucosides, sophorolipids, and rhamnolipids – which combine high functional efficiency with improved environmental compatibility.

1. Textile auxiliaries

Textile auxiliaries are utilized throughout multiple stages of textile product development, as illustrated in Figure 1. The primary raw materials for textile production originate from plant sources (such as cotton, flax, wood, and bamboo), animal sources (including silk and wool), and petrochemical sources (such as polyester, nylon, acrylic, and viscose). These categories correspond respectively to cellulosic fibers (natural), protein-based fibers (natural), and synthetic fibers [9].

Fibers are subsequently converted into yarns through various spinning techniques, including ring spinning, air-jet spinning, melt spinning, dry spinning, and wet spinning. At this stage, textile auxiliaries such as oils and antistatic agents are introduced to enhance processing performance and fiber quality.

The transformation of yarns into aesthetically refined and functionally enhanced fabrics involves several additional processes – namely sizing, weaving, pretreatment, dyeing, and finishing – during which textile auxiliaries continue to play a vital role in achieving the desired structural, functional, and visual properties of the final product [9].

Figure 1 Application of different textile auxiliaries in the development of textile products [9]

Potential textile auxiliaries include sizing agents, desizing agents, scouring agents, bleaching agents, penetration enhancers, leveling agents, color-fixation agents, thickening agents, binding agents, softeners, fluorescent brightening agents, as well as a range of functional finishing agents such as those providing wrinkle and shrink resistance, hydrophobicity and oleophobicity, stain repellency, flame retardancy, antistatic properties, antimicrobial and deodorizing effects, and ultraviolet (UV) resistance, among others. Furthermore, the development and application of textile auxiliaries are increasingly directed toward enabling the recycling and efficient degradation of waste textiles, thereby promoting environmental sustainability within the textile industry [9].

2. Surfactants – general

Surfactants, or surface-active agents, are compounds composed of a polar (hydrophilic) head group covalently linked to a non-polar (hydrophobic) tail. Based on the nature of the hydrophilic head group, surfactants are classified as anionic, cationic, nonionic, or zwitterionic. This classification is determined by the electric charge of the hydrophilic moiety, whereas the specific characteristics of the hydrophobic group further define the individual subclass of surfactant. Figure 2 provides a systematic overview of surfactant classification according to the charge of the polar (hydrophilic) segment of the molecule [10].
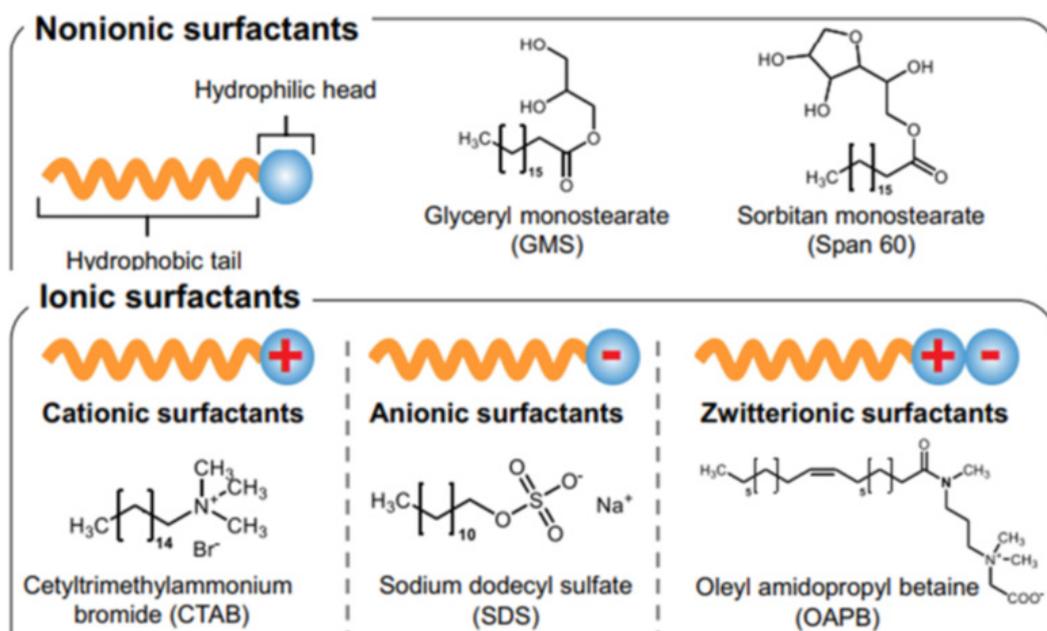

Figure 2. *Classification of surfactants [10]*

Surfactants are generally categorized according to the electric charge of their hydrophilic head group into four principal types: anionic, cationic, nonionic, and zwitterionic.

Anionic surfactants possess a negatively charged hydrophilic head group and encompass compounds such as sulfonates, sulfates, early synthetic detergents, and long-chain carboxylate soaps. Representative examples include alkyl benzene sulfonate, sodium laurate, and sulfosuccinate.

In contrast, cationic surfactants contain a positively charged hydrophilic head group and are

commonly derived from alkylpyridinium, imidazolium, or quaternary ammonium compounds. Typical examples include quaternary ammonium chloride and cetyl trimethyl ammonium bromide.

Nonionic surfactants are characterized by the absence of electrical charge on their hydrophilic head group, with water solubility arising from the presence of highly polar functional groups, such as polyethylene oxide chains. This category includes amine oxides, sulfoxides, phosphine oxides, pyrrolidones, alkanolamides, and widely utilized agents such as sucrose polyester and Triton X-100.

Finally, zwitterionic surfactants – also referred to as amphoteric surfactants – contain both cationic and anionic groups within their hydrophilic moiety. Their ionic behavior depends on the pH of the medium, allowing them to function as either anionic or cationic surfactants. Typical examples include 3-dimethyl dodecylamine propane sulfonate, sulfobetaine, lecithin, phosphatidylcholine, betaines, and sulfobetaines [10].

2.1 Surfactants and sustainable pretreatments in textile wet processing

Surfactants play an essential role in the textile and fiber industry, particularly within wet processing operations. Typically, the conventional sequence of pretreatment processes includes singeing, desizing, scouring, bleaching, and mercerizing, as illustrated in Figure 3. These procedures collectively prepare the textile substrate for subsequent dyeing, printing, and finishing stages [5, 10].

The specific sequence and parameters of these processes may vary depending on the intrinsic characteristics of the raw material. The singeing process – generally the first step in textile wet processing – removes protruding fibers from the fabric surface through controlled burning. This treatment enhances the surface smoothness and appearance of the fabric by eliminating fuzz and pills, improving light reflection without imparting a frosted effect, and providing better definition of the fabric structure. Additionally, singeing improves wettability, enhances dye uptake, increases print clarity, and reduces soiling and surface contamination. The process requires the use of water solely for quenching immediately after exposure to the flame, after which the heated fabric is typically transferred into a desizing bath [5, 10].
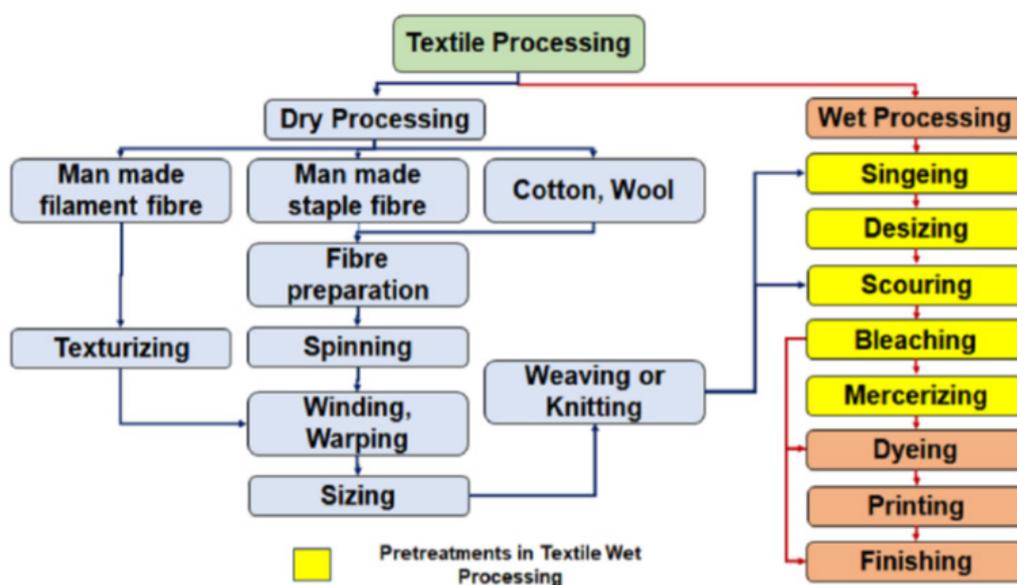

Figure 3. *Process flow chart for textile processing [5]*

In woven fabric production, an important preparatory operation known as sizing is carried out, during which warp yarns are coated with a starch-based film. The application of size enhances the tensile strength of the yarns, enabling them to withstand the cyclic mechanical stresses encountered during weaving. However, the presence of size renders the fabric hydrophobic, impeding further wet processing. Consequently, the removal of sizing materials prior to subsequent pretreatment operations is essential, a process referred to as desizing. Common desizing methods include enzymatic steeping, alkaline desizing, and oxidative desizing. Traditional desizing processes are characterized by high water and energy consumption, and the efficiency of size removal is often suboptimal. Therefore, developing resource-efficient desizing techniques with minimal energy and water use is critical for achieving sustainable textile manufacturing [5].

Typically, loom-state fabrics contain 8-12% impurities, including waxes, pectins, proteins, and mineral matter, all of which contribute to their hydrophobicity. The process employed to eliminate these natural and added impurities is known as scouring. Conventional scouring of cotton fabrics is performed in an alkaline medium (pH 10-12) using sodium hydroxide at approximately 100 °C for up to 24 hours. This method, while effective, requires substantial water and energy inputs, posing environmental and economic challenges [7].

Raw cotton also contains natural coloring impurities, which are removed through the process of bleaching. Both oxidizing and reducing agents are utilized for this purpose, though hydrogen peroxide is the most widely adopted due to its high efficiency and environmental compatibility. The alkaline bleaching of cellulose with hydrogen peroxide represents a well-established and environmentally favorable industrial practice in modern textile pro-cessing [8].

Mercerization is another key stage in textile finishing, aimed at improving luster, strength, dye affinity, and moisture absorption of cotton fabrics. During this process, the material is treated with a caustic soda solution (18-24%) for an impregnation period of 1-3 minutes. The fabric is maintained under tension to prevent longitudinal shrinkage. Fabrics subjected to tension mercerization exhibit greater luster and dimensional stability, whereas those processed under slack conditions display enhanced bulkiness and absorbency, albeit with reduced sheen [5-8].

2.2 Green Surfactants (Biosurfactants)

The extensive use of synthetic surfactants has led to numerous adverse environmental impacts, primarily due to their high toxicity and limited biodegradability. These substances negatively affect wastewater treatment efficiency and pose serious risks to aquatic ecosystems, including detrimental effects on microbial populations, fish and other aquatic organisms, as well as on the photochemical energy conversion efficiency of aquatic plants. With global surfactant consumption exceeding 15 million tons annually, and an estimated 60% ultimately entering aquatic environments, the need for environmentally benign alternatives has become increasingly urgent.

In this context, the origins, natural functions, and advantages of biosurfactants are gaining significant attention. Compared with synthetic counterparts, biosurfactants exhibit low toxicity, high biodegradability, and renewable biological origins, making them promising candidates for sustainable applications [11, 12].

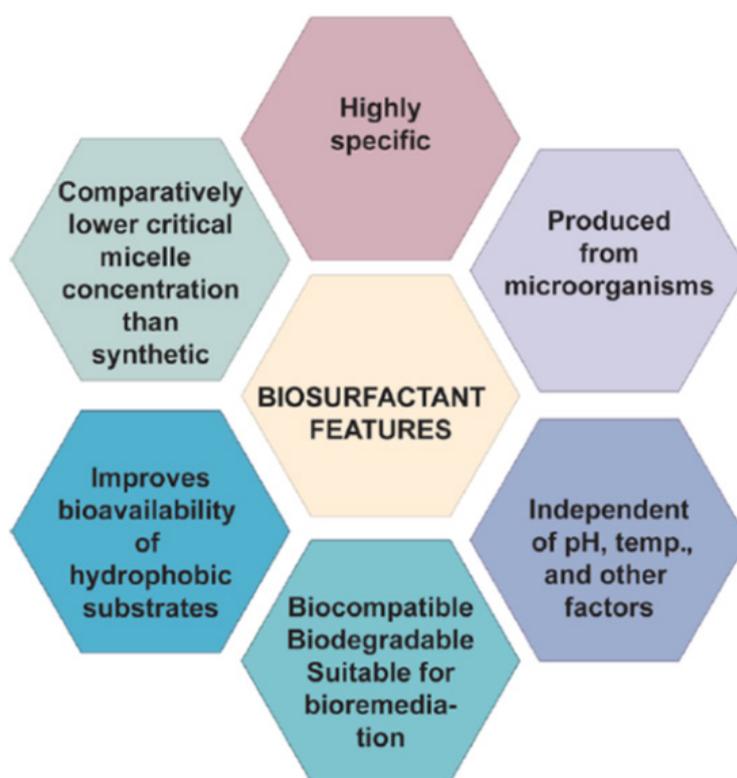The general properties of biosurfactants are illustrated in Figure 4.

Figure 4. *General properties of biosurfactants [12]*

2.2.1 Advantages of Green Surfactants (Biosurfactants)

Green surfactants, also known as biosurfactants, possess several advantages over conventional synthetic surfactants. They exhibit low toxicity and demonstrate enhanced stability and efficiency under extreme temperature and pH conditions. A key benefit of biosurfactants lies in their high biodegradability – they readily decompose into simpler, non-toxic metabolites, thereby minimizing environmental pollution. Due to these environmentally benign properties, biosurfactants derived from marine microorganisms have been successfully applied in various bioremediation and biosorption technologies [11].

In addition, biosurfactants play a crucial role in hydrocarbon degradation. Unlike chemical surfactants, they combine low toxicity, high biodegradability, strong surface activity, and high selectivity, while also forming stable emulsions. These features make them particularly suitable for enhanced hy-

drocarbon recovery applications, as their functional efficiency is retained under elevated temperatures, variable pH, and high salinity conditions. Overall, biosurfactants have been shown to exhibit superior surface and interfacial activity compared to conventional synthetic surfactants, further emphasizing their potential as sustainable alternatives in industrial and environmental processes [11, 12].

2.2.2 Limitations of Green Surfactants (Biosurfactants)

The large-scale production of biosurfactants remains technically challenging and complex. Certain biosurfactants may exhibit toxicity levels comparable to those of synthetic surfactants. In some cases, biosurfactants can compete with hydrocarbons as a preferential substrate, potentially limiting their effectiveness in specific applications. Furthermore, current production methods are not economically viable, posing a barrier to widespread industri-

al adoption.

To address these challenges, numerous research groups are exploring strategies to reduce production costs by utilizing readily available and renewable biological resources as feedstocks. The biotechnological processes required for biosurfactant synthesis are generally expensive, and downstream processing, including purification, represents a significant portion of the overall production cost. Nevertheless, a variety of biosurfactants have been successfully isolated, purified, and classified using diverse analytical techniques, providing a foundation for further research and industrial development [10-12].

3. Surfactant requirements for individual fibers and pretreatment processes

Surfactant recommendations by fabric type are as follows:

1. Cotton (cellulosic fibers)
• Challenges: Natural waxes, pectins, high alkali demand during scouring & bleaching.
• Recommended Surfactants:
- Non-ionic – stable in strong NaOH (fatty alcohol ethoxylates, EO/PO block copolymers).
- Alkyl polyglucosides (APGs) – eco-friendly alternative, good emulsifiers.
• Note: For mercerization, wetting agents with very low surface tension are critical.

2. Wool (protein fiber)
• Challenges: Lanolin, dirt, susceptibility to damage under alkali.
• Recommended Surfactants:
- Mild non-ionic surfactants – stable under lower pH, remove lanolin effectively.
- Amphoteric surfactants (betaines, sulfobetaines) – good at moderate pH, reduce fiber damage.
- Biosurfactants (rhamnolipids, sophorolipids) – gentle, biodegradable, effective degreasing.
• Note: Avoid harsh alkali-stable surfactants; wool refinement is usually milder than cotton.

3. Synthetic Fabrics (polyester, nylon, acrylic)

• Challenges: Oily spin finishes, hydrophobic surfaces, lower impurity load compared to natural fibers.
• Recommended Surfactants:
- Powerful emulsifiers – to remove lubricants/spin oils (non-ionic + anionic blends).
- EO–PO block copolymers – excellent dispersing under high temp (HT dyeing prep).
- APGs + amphoterics – eco-friendly, improve wettability of hydrophobic polyester.
• Note: Key role is wettability enhancement rather than heavy impurity removal.

When environmental considerations are taken into account, it is necessary to replace alkylphenol ethoxylates (APEO) with APGs or biosurfactants wherever possible. Also, enzyme-assisted desizing/scouring (e.g. amylases, pectinases) with mild surfactants should be used to reduce chemical loading. Closed-loop water supply systems benefit from biodegradable surfactants to reduce treatment costs [10-12].

Table 1 shows the framework for the environmental acceptability of surfactants for individual textile fibers.

Table 1. Surfactant Recommendations with Eco-Friendliness Ratings [7-9]

Fabric	Challenges	Recommended Surfactants	Eco-Friendliness Rating
Cotton	Natural waxes, pectins, high alkali load	• Non-ionic (EO/PO block copolymers) • Alkyl polyglucosides (APGs) • Strong wetting agents (mercerization)	+++ APGs, enzyme-assisted + EO/PO (synthetic, less green)
Wool	Lanolin, dirt, alkali sensitivity	• Mild non-ionic surfactants • Amphoteric surfactants (betaines) • Biosurfactants (rhamnolipids, sophorolipids)	+++Biosurfactants, mild amphoterics +Conventional synthetics
Synthetics	Spin oils, hydrophobic surfaces	• Non-ionic + anionic blends • EO–PO block copolymers • APGs + amphoterics for wettability	+++APGs + amphoterics +EO–PO blends (less biodegradable)

+++ = greener, renewable, biodegradable
+ = effective but less eco-friendly (synthetic, lower biodegradability)

4. Conclusion

Surfactants are essential components in the pretreatment of raw textile fabrics, significantly enhancing the efficiency and effectiveness of wet processing operations. By functioning as wetting agents, detergents, emulsifiers, dispersants, and stabilizers, surfactants facilitate the removal of both natural and added impurities, thereby improving wettability, absorbency, dye uptake, and overall fabric quality. Their molecular orientation at the water – fabric – air interface reduces surface tension, promotes capillary penetration of water, and ensures complete displacement of trapped air, which is critical for uniform treatment.

The careful selection of surfactants – particularly eco-friendly and biodegradable formulations – not only optimizes pretreatment performance but also aligns with sustainable textile manufacturing practices. Overall, surfactants are indispensable for achieving high-quality, functional, and environmentally responsible textile processing, forming the foundation for subsequent dyeing, finishing, and functionalization stages.

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