



Challenges in Wool Fiber Dyeing

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Review Article

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Abstract

This paper reviews the analysis of some properties of wool fiber and its dyeing challenges that can influence the outcomes of dyeing. It is relatively intricate to acquire the true color and the main source of a given problem is even more challenging. Its complexity is demonstrated by the different important chemical groups it has and the intermolecular forces of attraction between the linkages, the environmental demands on dyeing process, varied application areas, different important chemical groups present in the chain, fiber damage and permanent setting, presence of non-keratinous Proteins and due to the preparatory pretreatment process. Some approaches that could lead to progress in wool dyeing are discussed in this review and some alternative strategies are also proposed.

Keywords: Wool Fiber; pH; Protein; Wool Dyeing Challenges; Intermolecular Force

Introduction

Wool fiber is the most known protein fiber and its property is illustrated by its amino acid type, content and chemical structures present in the chain. Its amino acid content and side chain manages the significance effect of alkalis and acids on the fiber [1]. The structures of wool fiber have been studied widely over many years. The development of knowledge in this area has been catalogued in some wide reviews [2]. The most frequently used type of dye for wool fiber is acid dye in a wide shade gamut and excellent fastness properties [3]. According to the best pH value which is suited for its application; acid dyes are classified into two groups i.e. non-metalized acid dyes and pre- metalized acid dyes. Different group of dyes can be applied at different pH value based on the group which fits into pH from as low as 2.0 to 3.0 and as high as 6.0 [4]. The fastness properties; wash and light fastness are different from one group to another and according to the chemical structure of the fiber thus careful choice of dye is essential [5].

There are numerous challenges of wool dyeing during processing; nowadays different thoughts, ingenuity and on the side opinion are directly essential to conquer the challenges. Hence environmental demands will be more challenged on the dyeing process. Several advancements that might bring about improvement in wool dyeing are argued in this review and various other approaches are also considered [2-4]. Wool fiber is mostly applicable in the form of wide product areas as a result of its end use applications like knit wear, socks, upholstery, rugs, carpets, woven, filled bedding, yarns and blankets. Each and every one of these product areas tender significant challenges to the wool dyeing process [6]. Sometimes additional theoretical approach has been tailored to be done at present and in the future [7].

Current and future advancements in wool dyeing should thus assure several contending demands. Particularly end user demands, procedure demands, environmental demands and improvement demands [8-10]. Environmental, legal, ecological, care, protection, advancement, latest applications,

and healthiness are the key drivers of changes and challenges in wool dyeing and thus should be carefully controlled [11].

Wool Dyeing

In the composition of wool fiber, cuticle and cortical cells get-together and detained together by the cell membrane complex which is the main fiber forming polymer [12]. The properties of dyeing and diffusion coefficients are determined by the complex membranous structure of the cell wall, which is produced mainly through interior wool lipids. Wool cuticle cells (partly cover cells so as to enclose the cortex) are classified into three main layers as shown in Figure 1, namely the epicuticle, exocuticle and endocuticle [13]. The external casing of the level of the cuticle is enclosed

by a skinny membrane known as epicuticle. Beneath this lipid and hydrophobic epicuticle is the exocuticle, a sulphur-rich layer producing about the major part of the scale structure. Beneath the exocuticle layer, producing the rest of extent constitution is the endocuticle and subsequently a skinny cover of intercellular part [14,15].

Wool, in general with various additional proteins, will react through a bulky choice of chemicals and contains three major types of reactive group: peptide bonds, the side chains of amino acid residues, and disulphide cross links. The chemical reactions concerning these groups have been considered widely and discussed in different reviews [16] (Figure 1).

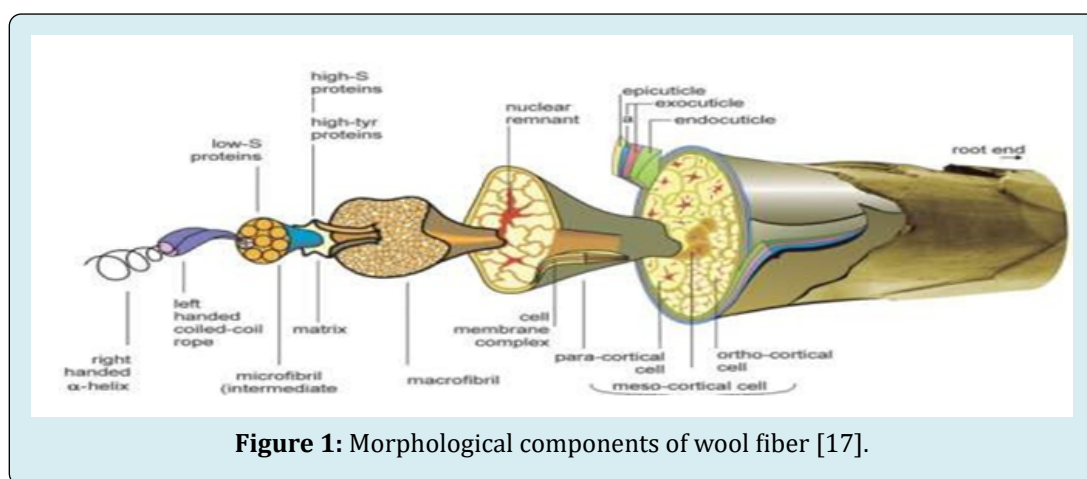


Figure 1: Morphological components of wool fiber [17].

Wool Dyeing Challenges

Most of the time wool dyeing challenges arise from chemical structures present in the chain, environmental demands, application areas, force of attraction between the linkages, fiber damage and permanent setting, and presence of Non-keratinous Proteins [18]. The complexity of wool fiber is mainly generated from its structure of important chemical groups and bond formed between the linkages i.e. intermolecular forces and hydrogen bonding. Sequentially first, there are hydrophilic peptide groups (i.e. -CO-NH-). Next, slightly negatively charged oxygen of the carbonyl groups (-CO-) and, thus, slightly positively charged hydrogen atom of the amino groups (-NH-) will form hydrogen bonds of other peptide groups. Finally, cystine linkage of the sulfur-containing amino acid able to form disulfide cross linkage which is liable towards better chemical stability, ensuing in a fewer dye absorption [19,20].

Epicuticle layer is highly lipid and hydrophobic nature due to the covalently bonded fatty acids and has also high quantity of Disulphide Bridge present in the outer layer

of the cuticle as a result there is high resistance to dye penetration from the epicuticle layer of the cuticle cell of the wool surface. Particularly in the printing and dyeing of wool, the hydrophobic nature of the wool surface is troubling and diffusion of dyes into the fibers is delayed [21]. Occasionally it is recognized that the hydrophobic epicuticle layer is the barrier to dye penetration by forming uninterrupted membrane around the fiber. The difficulty has also been illustrated to the cuticle and to the great cross-linking layer of the exocuticle [22].

All the implication on the environment of the difficulty was based on an ordinary principle that dyes must disperse through the cuticle cells to attain the fiber cortex (i.e. the trans-cellular route). A permanent stage of membrane cells, the cell membrane complex below the cuticle, produces a complex of penetrating canals to help intercede the impedance of the lipid barrier to dye diffusion, thereby assisting dye diffusion into the inside of the fiber [23,24].

Wool dyeing processes should operate on right-first-time processing principles and should follow standards,

minimizing all utilities (such as energy, chemicals water) to reduce costs, to save energy, to make it eco-friendly and using method of combination to get multi-functional performances [25]. The growing regulatory demands for small chrome, or no chrome, in dye house waste water has caused a decline in the use of after chrome dyes, with affiliated rises in the use of various acid-leveling, reactive dyes and metal complexes [26].

It is obvious that each regulatory procedure intended to eliminate chromium from structures of the dye and applying chrome in chrome dyeing might have severe consequences for the wool dyeing industry. Sometimes using metal-free reactive dyes will bring high color fastness and do not produce absorbable organic halides (AOX) might consequently develop in significance [27].

Wool dyers will as a result have to conquer their uncertainties about the use of reactive dyes and pursue the dyers of cotton and cellulosic fibers, who have made reactive dyeing such an achievement the technology of dyeing cellulosic fibers with reactive dyes is well recognized and a great deal can be proficient quickly in wool dyeing using reactive dyes. If wool dyers are eager to alter their predilection for after chrome dyeing [28,29].

To continue after chrome dyeing of wool fiber, the low chrome dyeing approach is ingrained. The amount of chrome in the overflowing process can be minimized by exploiting chrome dye exhaustion, reducing chrome adding, increasing chrome exhaustion in a new bath at pH chemically lowering Cr (vi) to Cr (iii) and interacting with wool carboxyl groups, dipping to offer several dilution results or by recovering, using a reputation bath methods for recurring shades with the equivalent dye liquor (which is the key infectivity basis) [30-32].

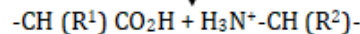
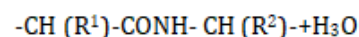
Investigations have revealed that Cr(iii) complex can be used as optional to Cr(vi) But in the widely used method is 1:2 metal complex dyes, or the utilization of metal-free, absorbable organic halides (AOX)-free reactive dyes, collectively with appropriate after treatments might establish to be much more fruitful from the environmental point of view. Improvement in reactive dyes for cellulosic fibers can also demonstrate importance for wool dyeing [32].

Various problems of wool dyeing can be due to the preparatory pretreatment process because it is the first stage in the wet processing stage especially dyeing and finishing and it depends on temperature, pH of the process, time and concentration of auxiliary chemicals. Hence Pretreatments for wool dyeing process have been recommended such as: enzymes, liquid ammonia mercerization, UV/ozone treatment, chitosan, low temperature plasma, liposomes and

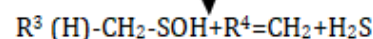
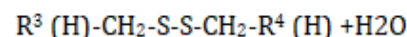
alcoholic alkaline or chlorine treatments [33,34].

Reactive disperse dyes used for dyeing polyester-wool blends can avoid the requirement of using carriers. Investigations going on the application of reactive disperse dyes including sulphonyl groups in supercritical fluid carbon dioxide has verified to facilitate covalent fixation of polyester and wool fibers can be attained, even though an aqueous-based method avoiding hydrolysis could be preferable and more extensively valid [35].

Wool Fibre Damage: Degradation to the wool fibre as a consequence of dyeing is usually accredited to chemical damage of the wool fibre [36]. At lower pH values (1.8–3.0), degradation arises mostly throughout hydrolysis of the amide bonds in the polypeptide chains (scheme 1). Hydrolysis of disulphide cross-links among the polypeptide chains arises at high pH values (scheme 2). The smallest wool damage has been reported to take place while dyeing in the pH range 3–5 [37]. This has been clarified by stabilization of the arrangement of the wool proteins within the iso-electric point of (pH 3.5–4.5) of the fibre. Below this situation, the concentration of salt linkages is at the highest level, and hydrolysis of amide and disulphide bonds is lowered.



Scheme 1: Hydrolysis of the amide bonds.



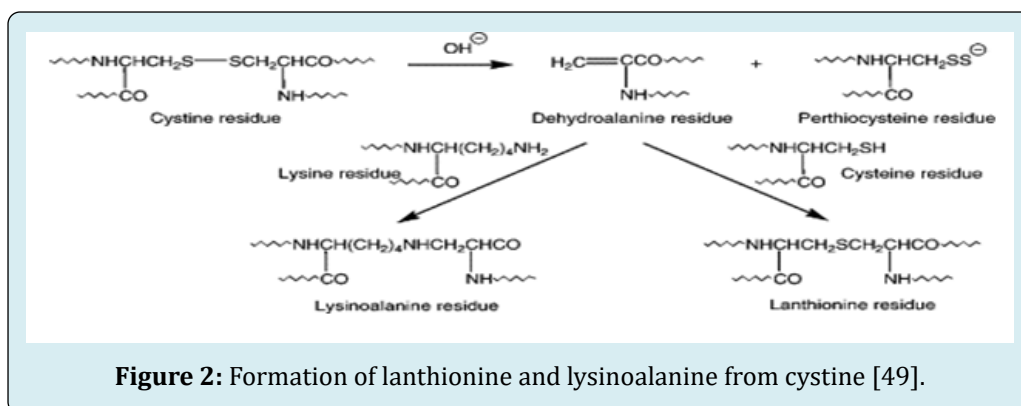
Scheme 2: Disulphide cross-links.

Conventional dyeing of wool fiber is carried out at extended periods or near at boil; this is essential to acquire good uniformity and penetration inside the fibre. Depending on the dyes and apparatus used, wool dyeing is carried out within the pH range 2–7. Under this situation, wool proteins can be adapted in several ways [38,39]. This damage frequently results in undesirable levels of yellowing [40]. Reduced productivity and yields in processing and impairment of the end-product performance, such as abrasion resistance, tear resistance and tensile strength [41].

Damage towards wool fiber in hot aqueous media, hydrolysis of peptide bonds, particularly at aspartic acid residues and at the amide group of tryptophan is due to the acidic solution [42]. But in alkaline dye liquors the chemical attack on wool fiber is much less careful and quicker than

that of the acidic conditions. Linkages, especially cystine are gradually hydrolysed under the acidic pH but Peptide bonds are broken down [43]. In the alkaline dye liquors, cystine can undertake β -elimination reaction towards generating lanthionine and lysinoalanine crosslinks [44]. These reactions are undertaken by a dehydroalanine intermediate, as shown in Scheme 3. The hydrolysis of

perthiocysteine residues produces hydrogen sulphide, to facilitate the reactions, causing a quick increase in the rate of fibre degradation in boiling dye bath liquors [45-47]. The formations of Lanthionine chemical are supposed to the embrittlement of fibre and a reduction in abrasion and tear resistance [48] (Figure 2).



Non-keratinous Proteins and Damage in Wool Fiber Dyeing:

The cell membrane complexes of a non-keratinous wool are the region at which the relative chemical and physical weakness in the arrangement of the fibre. The physical performance of wool fiber after dyeing is mainly affected by the preferential attack on these readily swollen fiber regions [50]. Usually wool fiber is dyed at boil, the hydrophilic proteins, known as 'wool gelatins' [51], can be taken out from the fibre. These soluble proteins have a small amount of cystine content, and are instigated from the non-keratinous regions. The yield of hydrophilic proteins is observed as a measure of the degree of fiber damage [52].

Permanent Setting: Permanent setting is moreover the main cause which is responsible for the impairment in the tensile strength properties of the wool fibre consequently with the dyeing properties. The polypeptide chains in the unstrained, straight, wool fibre are capable of becoming load-bearing at the same time throughout tensile testing, ensuing in a comparatively tough fibre. If a flattened wool fibre is stressed into a twisted arrangement proceeding to dyeing, the chains lying on the outside curve become extended, and those on the inside of the curve are compressed. Thiol- disulphide rearrangement during dyeing allows the strained chains to rearrange into more uniform, unstrained states, similar to those in the flat fibre [53].

If the dyed, curved fibre is flattening, there is the compressing of polypeptide chain outside the curve, and those that were on the inside of the curve are extended. The work of rupture required to sever the fibre is a bit less than for the original one. The chains that were on the inside of the fibre become load-bearing first and this cause's premature

failure in a tensile test [54-57].

Influence of Dye Bath pH on Fibre Damage: The ionic interactions in stabilizing the structures of wool fiber mainly depend up on the dye bath pH. The significance of dye bath pH on fiber damage throughout dyeing has been renowned in various reviews [16,58-60]. When wool is dyed within the iso-electric region of the fibre the intensity of damage is kept back to a bare minimum amount. Under this situation, the concentration of salt linkages is at the highest level, and therefore their stabilizing effect on the protein of wool fiber is maximum [61-63]. In the absence of further salts, the yield of soluble gelatin proteins appears to be independent of the effect of pH in the range of pH 3-8. A spectacular raise in yield has been established in liquors below the pH of 3. The quantity of gelatin protein extracted shows a bare minimum pH 3.5-5.0 [24,64].

Factors Affecting the Dyeing of Wool Fibers: Some of the factors that affect the dyeing properties of wool fiber include Fiber origin, Yarn type, Fabric structure, Water quality, Yarn/fabric preparation, Dye selection Temperature, Time, pH, Liquor ratio, Heating and cooling rate, Dosing of dyes and auxiliaries, Dye solution flow rate and circulation time, Pad pressure as discussed in different reviews [65-68].

Conclusion

Wool fiber has the most intricate chemical and physical structure of all fibers used in the textile industry. Its complex structure makes the fiber extremely flexible and used in a varied sort of products. Wool dyeing faces several challenges. The challenges may be posed by the environmental

demands on the dyeing process, varied application areas, different important chemical groups present in the chain, intermolecular forces of attraction between the linkages, fiber damage and permanent setting, presence of Non-keratinous Proteins and Some of the problems due to wool dyeing can be attributed to the preparatory pretreatment therefore creativity and lateral opinions are currently requisite to conquer the challenges and Some approaches that could lead to progress in wool dyeing are Use of specialty chemicals, Select suitable heat setting temperatures, Thorough relaxation of the material, Controlled tension and uniformity of batching during pretreatment, and Checking for rough patches in the machine.

Availability of Data and Materials

All data and materials are availed in the manuscript and no additional input is required.

Competing Interests

No competing of interest.

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