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Chapter

Antimicrobial Functional Textiles

Jamiu Mosebolatan Jabar

Abstract

Most textile materials are potential substrates for microbial growth. In order to make textile materials suitable as functional materials, the microbial growth must be reduced to the barest minimum or quenched due to their undesirable effects; such as offensive odor, discoloration, degradation, mechanical strength reduction etc. Chemical finishing of textile materials (such as application of silver nanoparticles, quaternary ammonium compounds, chitosan, some synthetic and natural dyes to mention a few) is capable of imparting this functional property among others to the textiles. Although, mechanism of antimicrobial activities of treated textiles is yet to be clearly defined, but in most cases, antimicrobial action of treated textiles usually occurs through interaction of cation in antimicrobial agents with anionic charged microbial cell wall. Antimicrobial treated textiles are usually less prone to offensive odor, discoloration, deteriorating mechanical properties and make the consumers free of skin problems. In fact, they can be used as cheap materials for production of hospital gowns, hand gloves and face masks for containing microorganism borne diseases, such as the current Covid-19 pandemic.

Keywords: Antimicrobial, Cell wall, Chemical finishing, Covid-19, Offensive odor, Skin, Textiles

1. Introduction

Wide varieties of textile materials are available in the market. Each of them is meant for a particular purpose; ranging from covering nakedness, decoration to medical purpose [1]. Moisture content (MC) and moisture regain (MR) are some of the important properties to be considered for chosen these materials for intending purpose. Generally, natural fibers are of relatively high MC and MR when compared with man-made fibers [2]. Hence, they are more prone to microbial attack than their man-made counterparts, due to combination of fiber's moisture and warm environment (body temperature between 36 and 38°C) that favors microbial growth on textile substrates.

Therefore, many textile materials especially those from natural source are potential media for microbial growth in their unmodified form. The major demerits of microbial growth in textile materials are offensive odor, discoloration, staining and mechanical strength reduction. At times, microbial growth on clothing materials may cause dermal infection on the skin of the wearers [1]. These effects are more likely to occur in natural textile materials. They are disliked by textile manufacturers and therefore, need to be avoided to the barest maximum [3]. Several researchers have tried in one way or the other to work on textile fibers (especially the natural fibers) in order to reduce the rate at which they get attacked by microorganisms. Bhuiyan et al. [3] reported *Lawsonia inermis* L dyed jute fabric to have a good microbial inhibition and when surface modified with chitosan the percentage inhibition greatly improved. Hong [4] observed that tannin mordanted spent coffee grounds dyed wool fabric inhibited above 95% of microbial growth. Jabar et al. [1] reported that 1, 3-bis[(furan-2-l) methylene]thiourea functional dyed wool and cotton fabrics have excellent fungi inhibition.

This section will focus on after-treatments modification of natural fibers, since they are more associated with microbial attacks.

2. After-treatment modification of textile materials

The after-treatment of these fibers is meant to modify their surfaces for combating microorganisms when in contact with them. Although, some of the chemical finishing agents do not only modify the surface of textile materials but as well form chemical bond with textile matrix. The commonly used reagents for production of antimicrobial textile materials are silver compounds/composites and quaternary ammonium compounds [5]. High cost and environmental awareness on these compounds made researchers to be looking for low cost and environment friendly alternative from naturally derived materials. The reagents reported for this purpose are chitosan, natural and synthetic dyes [6].

How these reagents perform their roles as antimicrobial agents on textiles will be discussed in the below sub-sections.

2.1 Silver compounds/composites

Silver in form of chloride, nano-particle, organo-silver or composite is used as antimicrobial agent for textile material. The application of these antimicrobial agents to man-made textile materials (silk inclusive) can be through pad-dry, coating, spray, foam technique or can be done directly by their inclusion in spinning dope during spinning operation. Their application on natural textile materials is often done through exhaustion in aqueous solution or done during dyeing operation [7]. Addition of stabilizing agent (e.g. propylene glycol, sodium salt of alkyl sulfate, polyethylamine, polyethylpyrrolidine, dendrimers etc.) to any of these antimicrobial agents during aqueous application performs triple functions. Foremost, it prevents precipitation/agglomeration of the antimicrobial agent in solution. Polymeric stabilizing agents form silver–polymer giant molecules that enhance performance of antimicrobial agent in natural textile substrates and lastly, it reduces probability of Ag^+ bleeding out from textile substrates [2].

The way and manner silver performs anti-microbial function in textile substrates is yet to be clearly identified [2]. The general belief is that Ag^+ will be released slowly from silver–polymer complex in textile matrix or surface and diffused into the microbial cell(s) when in contact with micro-organisms. Diffusion of Ag^+ into the microbial cell's site hinders activities of microorganisms and finally destroys them. This action is usually a very fast action that occurs within few minutes of contact with microorganisms. Although, silver radical (Ag^*) may be formed along with Ag^+ released from silver–polymer complex or formed separately instead of the release of Ag^+. When in contact with microorganisms, Ag^* attacks microbial cell's protein structure, destroys it and kills the microorganisms. Although, silver antimicrobial agent applied to natural textile substrates through exhaustion are usually active for more than fifty cycles of laundry operation, but the slow release of Ag^+/Ag^* from silver–polymer complex results into reduction in quantity of available silver in the functional textiles [5]. The one applied through pad-dry, coating, spray or foam technique may no longer active after few laundry operations. These antimicrobial agents are used for production of cloths for active underwear garment, socks and sport wears. They are equally useful in production of antimicrobial cloths for medical applications, such as towels, wound dressing, mattresses spread sheets and pillow cases [7].

Silica matrix stabilizes silver nanoparticles (**Figure 1**) induced exceptional antimicrobial property onto textile substrates. Silver nanoparticles are weakly held within the silica matrix by physical forces and the release of Ag^+ for attacking microorganism is gradual over a long period of time. Application of antimicrobial film prepared from mixture of silver nanoparticles and fluoroalkyl siloxane (FAS) on textile substrates induces a better antimicrobial functional property on textiles [2].

It is essentially useful in production of clothing materials for medical applications and home textiles [3].

However, high cost of silver containing substances made researchers to be looking for low cost and effective alternatives as antimicrobial agents for inducing antimicrobial property onto the textile substrates [5].

2.2 Quaternary ammonium compounds

Quaternary ammonium compounds (**Figure 2**) are applied to textile substrates as antimicrobial agents through sol–gel chemistry.

Organic–inorganic gel network structure of quaternary ammonium compound can be applied in continuous liquid phase through pad-dry-cure process to form thin film of about 10 nm thickness on textile surface [2]. Prior to curing process between temperature of 140 and 170°C, the thin nano-composite of quaternary ammonium compound film links to textile substrate (e.g. cotton) through covalent bond formation (**Figure 3**) [6–7].

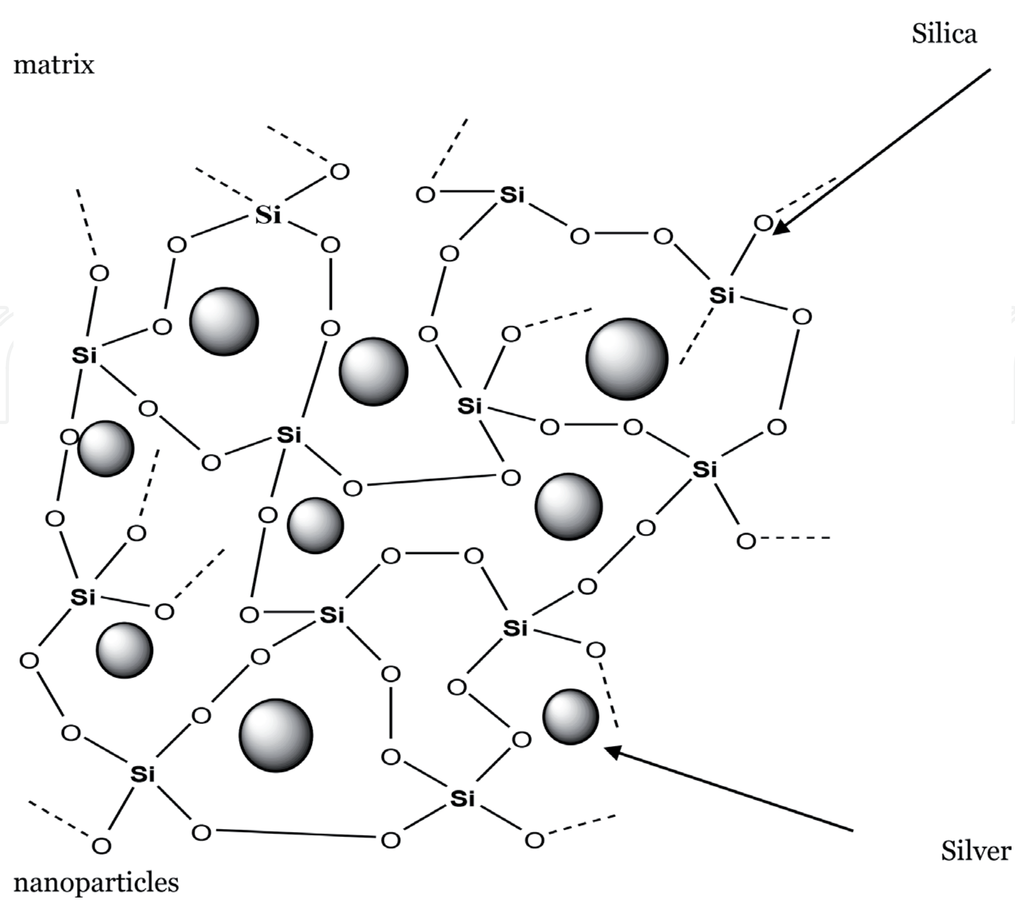

Figure 1.
Silver nanoparticles weakly held in silica matrix.

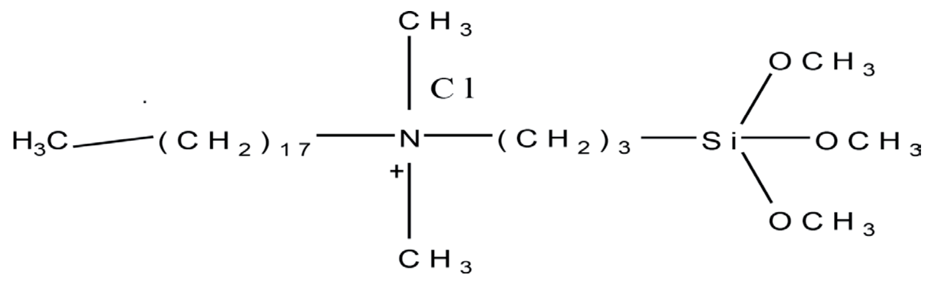

Figure 2.
Trimethylsilyl-propyldimethyloctadecyl ammonium chloride.

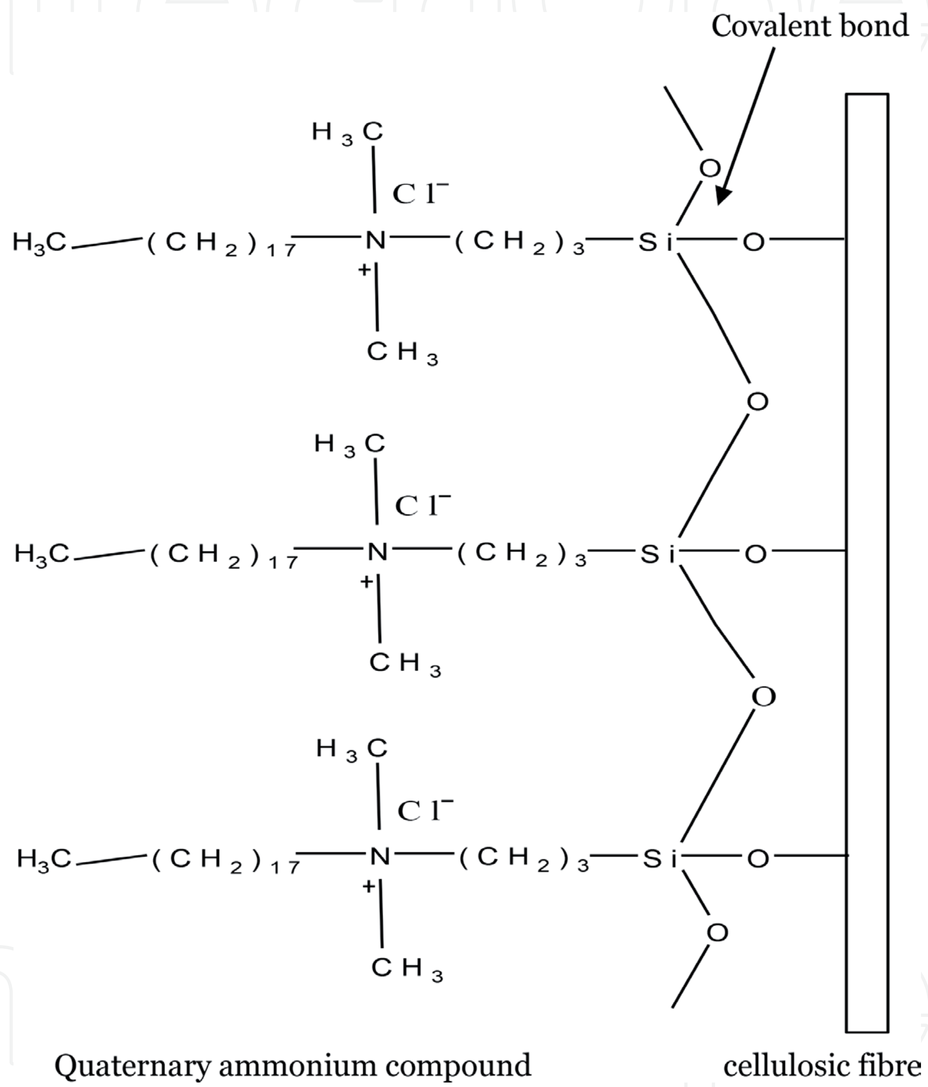

Figure 3.
Propyldimethyloctadecylammonium chloro silicone pad-dry-cured textile substrate.

The covalent bond formed imparts excellent durability to the textile through strong bond of attraction between the antimicrobial thin film and textile substrate. It also gives a control action of cationic quaternary ammonium compound against microorganism when in contact with textile surface. The cationic charge on the antimicrobial agent formed complex with anionic charged microbial cell membrane, thereby hindering microbial activity and finally kill the microorganism [2]. Just like in Ag^{+} nanoparticles treated antimicrobial textiles, Quaternary ammonium compound treated cloths are equally useful for medical and domestic applications such as towels, wound dressing, mattresses spread sheets and pillow cases, mattresses and window blind.

Recent investigation has shown possibility of preparing antimicrobial precursor mixture from combination of quaternary ammonium compound and fluoroalkyl siloxane (**Figure 4**). Application of this antimicrobial mixture on textile substrates inhibits microbial growth very effectively. The unique features of this antimicrobial mixture besides the primary property are lowering tendency of adhesion of microorganism to textile substrates (by lowering fiber surface energy), importation of oleophobic and superhydrophobic properties to the textile fibers [2]. Therefore, it can be said that textile material treated with this mixture will possess multifunctional properties for use in production of out-door textiles (non-skin contact textiles), such as marquees, tarpaulins and awnings.

2.3 Chitosan

Chitosan (2-amino-2-deoxy- (1, 4)-*β*-D-glucopyranan) is a product of partial deacetylation reaction of chitin (**Figure 5**) obtained from shell of snails, crayfish, lobsters, cuttlefish, fungi cell walls, crabs and shrimps. It is most abundant natural polymer after cellulose. Chitosan is a polysaccharide with molecular structure similar to cellulose, apart from presence of nitrogen in its structure [6].

Chitosan has distinctive properties, such as antimicrobial activity, biodegradability, non-toxicity, solubility in both mineral and organic acids [7]. These properties account for its suitability as antimicrobial agent in textile production. Just like in Ag^+, the mechanism of its antimicrobial activities is not clearly understood. Although, it is generally believed that interaction of positively charged

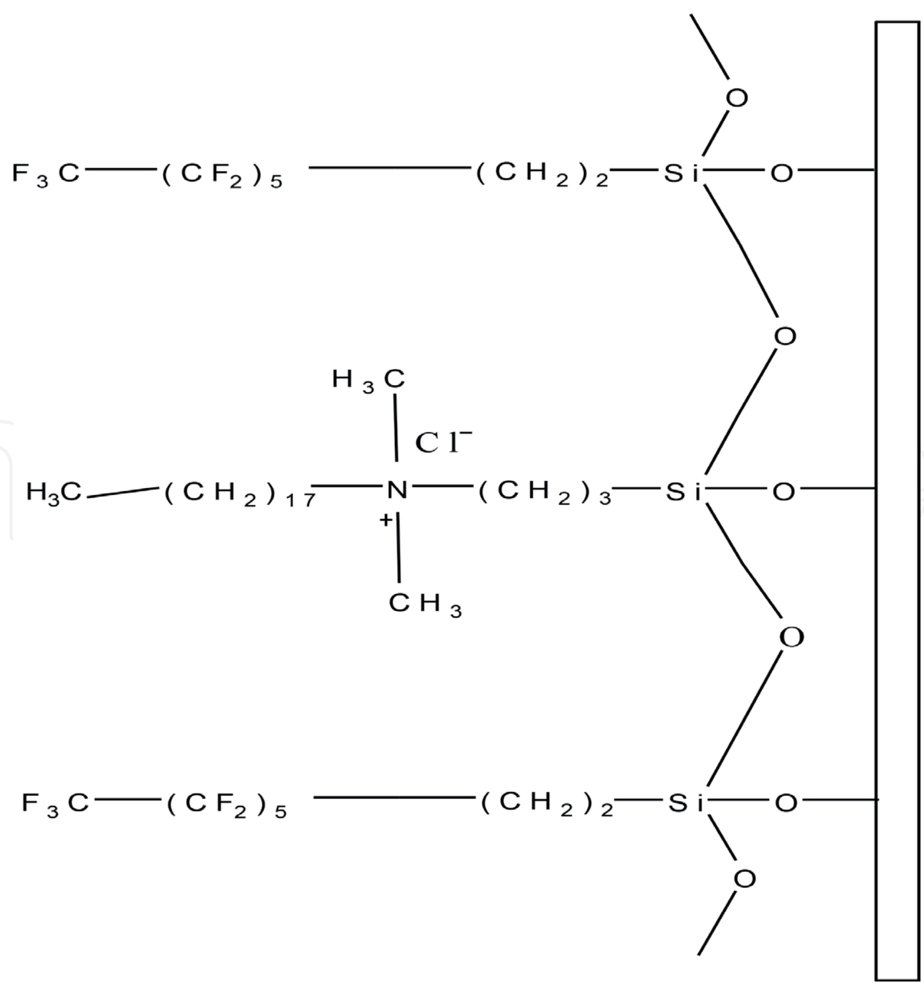

Figure 4.
Antimicrobial mixtures on cellulosic fiber.

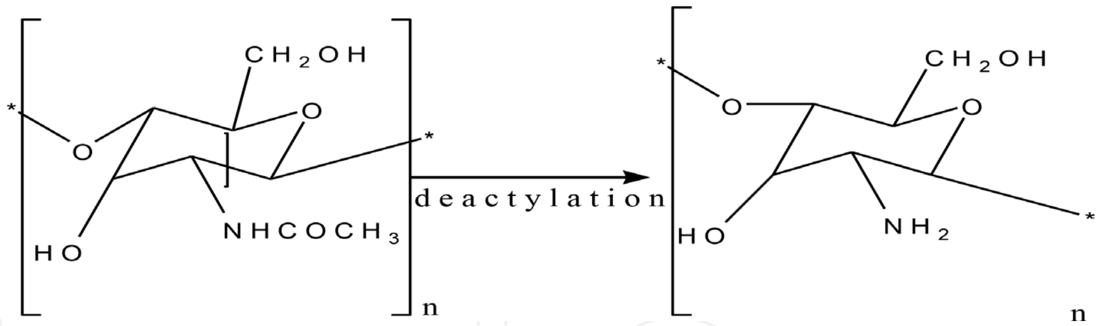

Figure 5.
Deacetylation of chitin.

chitosan amino group with negatively charged cell membrane of microorganism leads to inhibition of microbial growth and eventually results into their death [2]. Antimicrobial activity of chitosan can also be through binding of microbial DNA by chitosan, which results into microbial cell protein synthesis inhibition. Microorganisms' inability to biosynthesize protein in chitosan environment leads to their death [7].

Chitosan can be applied onto textile fibers through exhaustion process and made crosslinked giant molecule in fiber matrix through curing process (other possible mode of applications are pad-dry, pad-dry-steam and pad-batch) [5]. It is first dissolved in acidic medium (of a known concentration) by introduction of a known weight of biopolymer in glacial acetic acid (known volume and concentration) for 1 h (ripening time) and the mixture stirred mechanically for 2 h for complete dissolution of chitosan. If the curing process will be through radiation, a known quantity of photoinitiator will be added and required volume will be made through addition of distilled water [7]. But if curing process will be through thermal, required volume of distilled water will be added without addition of photoinitiator. Textile fiber will then be inserted into the prepared chitosan solution to be coated through exhaustion process, followed by drying at 70°C for about 1 h and cured for 30 min in presence of ultraviolet radiation (for photo chitosan cured fibers) or at 170°C (for thermally cured fibers-chitosan) [5]. During the curing process chitosan enters into fiber matrix in linear biopolymer form and undergoes crosslinking reaction. The curing process makes the treated fibers durable, even after several laundry operations [7].

Like in the case of quaternary ammonium compounds, functional antimicrobial property of mixture of chitosan and silver nanoparticles has been reported by researchers to be better than that of individual agent. Therefore, coating textile fibers with mixture of chitosan and silver nanoparticles imparts very good antimicrobial property onto them [4]. Chitosan or chitosan/Ag^+ coated textile materials are very good as surgical garments, gloves and face masks. As a matter of fact, textile materials made of these antimicrobial agents are going to be good wears for Covid-19 front line workers and general populace to combat the current pandemic virus.

2.4 Synthetic dyes

These are developed in laboratory, from existing natural coloring materials to alleviate demerits fund in natural dyes/pigments. Some of the demerits of natural coloring matters are poor fastness properties, low yield, irreproducibility, lack of uniformity and high cost. Therefore, synthetic coloring matters are relatively cheap, reproducible and have uniform hue, very good to excellent fastness properties and high yield [1, 8]. Previous studies reported bio-based synthetic dyes to possess antibiotic, antiviral, antifungal, anti-oxidant, anticancer, anti-malarial, anti-inflammatory and ultraviolet protective properties [9].

These coloring matters are many and they are mostly applied onto textile fibers through exhaustion process. Pigments are mostly applied through coating or printing process [8].

It was reported by researchers that many synthetic dyes (especially Schiff base dyes) have antimicrobial property. In previous study, it was reported that synthesized novel 1, 3-bis[(furan-2-l) methylene]thiourea functional dyed wool and cotton fabrics have above 70% anti-fungi inhibition against *Fusarium oxysporum, Colletotrichum gloeosporioides* and *Cercospora zeaemaydis* fungi and moderate antibiotic property against *Staphylococcus aureus* (Gram-positive), *Pseudomonas aeruginosa* and *Xanthomonas axonopodis* (Gram-negative) bacteria. This study was jointly carried out at Textile and Polymer research laboratory, Department of Chemistry, Federal University of Technology, Akure, Nigeria and Industrial and Environmental Unit, Department of Chemical Sciences, College of Natural and Applied Sciences, Fountain University, Osogbo, Nigeria.

2.5 Natural dyes

Natural dyes are generally soluble in water and as a result, they are usually applied onto textile fibers through exhaustion technique [8]. Due to environmental awareness, there is interest restoration in the use of natural dyes for coloration of textiles. Besides this major reason of their application on textiles, many of them do impart antimicrobial property onto the textiles. The way and manner of their antimicrobial activity on textile fibers has not been clearly defined. Although, it was reported by Soares et al. [10] that antimicrobial active compounds in dyes are phenolics, terpenoids and anthraquinones. The cationic charge on these compounds interacts with anionic charged microbial cell wall to resist cell growth and facilitate microbial death.

Poor fastness properties that are associated with natural dye dyed fibers are usually overcome through the use of metal salts or compounds as mordant. If metal salt like silver nitrate is used as mordant prior to dyeing of textile material with natural dye, dual enrichment given to the dye on fiber matrix are formation of covalent bond between dye molecule-metal ions and fiber matrix and antimicrobial property enhancement of the natural dye dyed fibers [2]. If natural mordant like chitosan solution is used as mordant prior to dyeing process of the fiber, amino cationic charge on chitosan boosts antimicrobial property of the dye through degradation of proteineous microbial cell wall of microorganism. It equally enhances color strength of the dyed fibers [3]. Antimicrobial synergic effect of chitosan and natural dye called henna on jute fibers was studied against *Staphylococcus aureus* and *Klebsiella pneumoniae* by Bhuiyan et al. [3]. They reported that chitosan mordanted dyed fabrics have greater than 90% bacterial reduction. If chitosan is not crosslinked in the fiber matrix, dyed fiber mordanted with chitosan may no longer durable after the first laundry operation. Hence, natural dye dyed fibers mordanted chitosan can be used as wound management fibers in the hospital. Whereas, those mordanted with silver compounds are durable after several laundry operations due to their covalent bond with fibers. Therefore, they can be used in production of under wares, socks, hospital wares, face masks etc.

3. Application of antimicrobial agents onto textile fibers

The antimicrobial chemical reagents can be applied onto the textile fibers through (i) exhaustion and (ii) coating/dry pad techniques depending on interaction of fiber matrix with antimicrobial agents [10].

3.1 Antimicrobial exhaustion on textile fibers

Antimicrobial agents that chemically react with fibers are applied on fibers through this technique. Antimicrobial natural and synthetic dyes are usually applied through this technique [1].

Exhaustion technique involves solubilization of antimicrobial agent in a suitable solvent, immersion of the fibers in the solution and stirs the mixture for specific period of time at a particular temperature. At the end of reaction period, the treated fibers will be washed under running tap water to get rid of unattached antimicrobial molecules [11].

3.2 Coating/dry pad application of antimicrobial agent on textile fibers

Antimicrobial agents that cannot bind chemically with textile fibers are applied onto fibers through coating/dry pad technique. Chitosan is a good example of antimicrobial agent that can be applied onto fibers through this technique. A detail on this technique has been discussed in Section 2.3.

4. Fibers with inherent antimicrobial properties

The fibers reported for inherent antimicrobial properties are flax, bamboo, hemp and kapok cellulosic fibers with cationic functional group according to Soares et al. [10]. Others are wool and chitosan fibers with amine functional groups [2]. The cellulosic antimicrobial fibers function through interaction of their polycationic functional group with anionic components of microbs resulting into permeability of the microbial cell wall, which eventually leads into death of microorganisms.

The textile fibers with amine functional group (wool and chitosan) resist microorganisms through linkage of cationic amine group with thio group of microbial cellular enzymes, hindering growth and activities of microorganisms and of course results into their death [1]. Chitosan yarns prepared through wet spinning of dilute acetic acid solubilized chitosan fibers in appropriate alkaline coagulating bath are usually used for industrial scale production of wound bandage. Large scale production of fabric from chitosan fibers is yet to be reported due to low mechanical strength of chitosan yarn. In medical wound dressing and sutures, chitosan performs its wound healing ability through diffusion to the site of bacterial growth, reacts with anionic function group in bacteria and puncture the cell wall to kill the bacteria [2].

5. Conclusion

Treatment of textile fibers with antimicrobial agents is very essential because textile materials are potential media for microbial growth. Microbial growth is undesirable to textiles due to formation of offensive odor, discoloration and degradation. It also makes the textile consumers uncomfortable and occasionally it causes skin problems. Treatment of textiles with silver compounds/nanoparticles, quaternary ammonium compounds, chitosan, synthetic and natural dyes or combinations of these agents alleviates textile materials from aforementioned inherent microbial demerits. Antimicrobial functional textiles are good materials to be used in production of surgical gowns, gloves, socks and body masks for containing microbial borne diseases like ebola and pandemic Covid-19.

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Conflict of interest

The author declares no conflict of interest.

Author details

Jamiu Mosebolatan Jabar
Textile and Polymer Research Laboratory, Chemistry Department, The Federal University of Technology, Akure, Nigeria

*Address all correspondence to: jmjabar@futa.edu.ng

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