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Application of Antimicrobials in the Development of Textiles

[1]Ali Elshafei and [2]H.T. El-Zanfaly
[1]Department of Microbial Chemistry, Genetic Engineering and Biotechnology Research Division, National Research Center, Dokki, Cairo, Egypt
[2]Department of Water Pollution Control, Environmental Research Division, National Research Centre, Dokki, Cairo, Egypt

Corresponding Author: Ali Elshafei, Department of Microbial Chemistry, Genetic Engineering and Biotechnology, Research Division, Al-bhous Street, Dokki, Cairo, Egypt Tel: 00202-24143149

ABSTRACT

The growing use of polyester, nylon and acrylics which have inherent resistance to microbial decomposition, came into wider use to replace cotton in many industrial fabrics. In addition, the consumers are now increasingly aware of the hygienic life style and there is a necessity for a wide range of textile products finished with antimicrobial properties. The new technological developments for imparting antimicrobial permanent finishes, of the non-leaching type, to different textiles, including the man-made one, would help reduce the negative impact effects and possibly could comply with the consumers requirements. Hospital materials such as theater drapes, gowns, masks, sheets and pillowcases are known to be major sources of cross-infection, so all textile materials used in hospitals should prevent or minimize or transmission of infectious diseases. This study reviews some recent approaches of antimicrobial finishing textiles and their properties.

Key words: Antimicrobials, textiles finishing, public health

INTRODUCTION

Microbial damage of fabrics is a common problem in many parts of the world and microbial-contaminated fabrics in hospitals are known to be the major source of cross infection (McCullough and Schoenberger, 1991; Gerberding *et al*., 1987). Postoperative infections, in particular, are the most common hospital-acquired infections. Operating staff and patients could represent source of infection transmission, since bacteria can, by a variety of routes, find their way into an open wound and cause sepsis. Therefore, surgical gown, towels, pillowcases and blanket materials is better to have antimicrobial properties. Microorganisms cause problems with textile raw materials and processing chemicals, wet processes in the mills, roll or bulk goods and finished goods in storage and transport. This can be extremely critical to a clean room operator, a medical and food processing facilities or it can be an annoyance and esthetic problem to the athlete or normal consumers. The economic impact of microbial contamination is significant and the consumer interests and demands for protection are high.

Several researchers have used antimicrobial finishes to provide fabrics with barriers against microorganisms. The application of antimicrobial agents to textiles is important to prevent microbial attack which results in degradation of the textile and to obtain the aesthetic, hygienic or medical functions. Antimicrobials are used on textiles to control bacteria, fungi, mold, mildew and algae and the problems of deterioration, staining, odors and health concerns that they cause (Olson *et al*., 1984; Cho and Cho, 1997).

The term antimicrobial refers to a broad range of technologies that can provide varying degrees of protection for textile products against microorganisms. Antimicrobials are very different in their chemical nature, mode of action, impact on people and the environment, in-plant-handling characteristics, durability on various substrates, costs and how they interact with microorganisms. Thousands species of microorganisms are found everywhere in the environment and on our bodies. These organisms had negative effects on producers, retailers and users of all kinds of products. This manuscript reports some applications for imparting antimicrobial activity onto fabrics.

ANTIMICROBIALS MOBILITY

The vast majority of antimicrobials study by leaching or moving from the surface on which they are applied. This is the mechanism used by leaching antimicrobials to poison a microorganism. Besides affecting durability and useful life, leaching technologies have the potential to cause a variety of other problems when used in garments. These include their negative effects because they can contact the skin and potentially affect the normal skin flora, cross the skin barrier and/or have the potential to cause rashes and other skin irritations.

The antimicrobial agents with completely different mode of action than the leaching technologies is a molecularly bonded unconventional technology (Gettings and Triplett, 1978). This technology has a mode of action that relies on the technology remaining affixed to the substrate-killing microorganisms as they contact the surface to which it is applied. One of the advantage of this technology is that it does not leach or diminish over time. The application of this technology led to the polymerization of the antimicrobial agent with the substrate acquiring the surface antimicrobial effects. This type of non-leaching antimicrobial technology is used in textiles that are likely to have human contact or where durability is of value. Many investigators have accomplished this type of surface modification by electron beam grafting of acrylic monomers with quaternary ammonium compounds to hydroxyl active surfaces (Table 1).

Table 1: Comparison between leaching and non-leaching- textile finishes

Leaching textile finishes	Non-leaching textile finishes
Leach and leave the textile surface on which they are applied enter or react with the microorganism acting inhibitor.	Do not leach or diminish over time. Molecularly bonded and chemically technology, killing microorganisms as they contact the surface as an to which it is applied.
Had negative effect on durability.	Do not affect durability and remaining affixed to the substrate.
Cause a variety of other problems when used in garments.	This technology is used in textiles that are likely to have human contact or where durability is of value.
Cross the skin barrier and have the potential to cause rashes skin irritations.	This technology does not cross the skin barrier and does not and other cause rashes or skin irritations.
Allow the adaptation of microorganisms to potential toxicants, if to sub-lethal doses.	Do not pose the risk of creating adaptative resistant they are exposed microorganisms.
They are used up in the process of working or in random misses.	This technology has been used without any human health or wasted environmental problems in manufacturing facilities or in actual end use situations.
Leaching antimicrobials are strongest in the textile surface and weakest the farther it travels from it.	Stay affixed to the textile and, on a molecular scale.
No easy way to tell whether leaching antimicrobials are present on a product and chemical verification tests are time consuming.	With the bound antimicrobial technology, a simple staining test can be performed in a short time to indicate the presence of antimicrobials.
The antimicrobial leaching functions on the fabrics are durable in repeated laundering process.	The antimicrobial activity of the non-leaching treated fabrics, are non-maintained after laundering many washing cycles.

The unconventional antimicrobial technology used in the textile industry does not leach but instead remains permanently affixed to the surface. This is applied in a single stage of the wet finish process; the attachment of this technology to surfaces involves two means. First (and most important) is a very rapid process, in which the substrate (fabric, fiber, etc.) is coated by the cationic species (physisorption). In the second, the substrate is bonding with the cation of the antimicrobial agent through a chemisorption process (Gettings and Triplett, 1978).

TECHNOLOGIES FOR IMPARTING ANTIMICROBIAL ACTIVITY

A wide number of antimicrobial compounds are now in use but differ in their mode of action. The following demonstrates some applications for imparting antimicrobial finishes onto fabrics:

Fibres finished with quaternary ammonium salts bind microorganisms to their cell membrane and disrupt the lipo-polysaccharide structure resulting in the breakdown of the cell. An effective two-stage method has been developed by Shalaby *et al.* (2008a), for imparting antimicrobial properties to regular-polyethylene terephthalate (R-PET), polyethylene glycol- modified-polyethylene terephthalate (PEG-M-PET), R-PET/Cotton blend (R-PET/C) and PEG-M-PET/Cotton blend (PEG-M-PET/C) fabrics. The method consists of partial hydrolysis of the fabrics to create carboxylic groups in PET macromolecules followed by subsequent reaction with dimethylalkylbenzyl ammonium chloride (DMABAC) under alkaline conditions. The reaction conditions such as pH, reaction temperature and time, carboxylic content and DMABAC concentration were studied. Characterization of the finished fabrics was carried out through Scanning Electron Microscopy (SEM) and Fourier Transform Infra Red spectra (FTIR). All the modified PET fabrics showed excellent antibacterial activity towards Gram-positive (*Bacillus mycoides*), Gram-negative (*Escherichia coli*) and nonfilamentous fungus (*Candida albicans*). The achieved antimicrobial functions on the PET fabrics are durable in repeated laundering processes. Even after laundering 10 times the fabrics could still provide more than 85% of its antimicrobial activity against *B. mycoides, E. coli* and *C. albicans*. In another study (Shalaby *et al.*, 2008b), a simple, efficient and practically applicable functional approach for improvement antimicrobial properties of nylon-6 fabrics and increase the washing durability of biofunctions was developed. This finishing approach is based on grafting of the fabrics with methacrylic acid (MAA) to create additional carboxylic groups in nylon-6 macromolecules, followed by subsequent reaction with dimethylalklbenzyl ammonium chloride (DMABAC) solution under alkaline conditions. The carboxylic groups react with cationic agent through ionic interaction which led to the immobilization of QAS on nylon-6 fabrics. This immobilization was proofed through determination of nitrogen content, applying Scanning Electron Microscopy (SEM) and FTIR microscopy. The antimicrobial assessment of regular and grafted with PMAA nylon-6 fabrics treated with DMABAC revealed that both types of fabrics are characterized before washing, by quite strong biocide effect on *Bacillus mycoides, Escherichia coli* and *Candida albicans*. The role of grafting nylon-6 fabrics before treatment with salt on durability of antimicrobial functions seems to be more significant as the samples were repeatedly washed. Even after Laundering 10 times the grafted samples could still provide 80, 100 and 87.5% microbial reduction in numbers against *B. mycoides, E. coli* and *C. albicans*, respectively, in contrast with 42.6, 65.6 and 42.5% in case of regular nylon-6 fabrics.

Enzymatic applications are of growing importance especially to textile fields ranging from fabric pretreatments to fabric destruction (Sarkar and Etters, 2004). Immobilization of various industrial enzymes onto or within the textile matrix can be achieved via adsorption, covalent bonding and entrapment; to get increased activity and stability in various applications as well as to build new

functionalized textile products (Howell and Mangat, 1978). A new technology for building new functionalized textiles was applied onto ester-crosslinked as well as Cu-chelated cotton fabrics by immobilization of α-amylase, laccase and alkaline pectinase for imparting antimicrobial properties. Proper conditions for attaining higher extent of enzyme-loading and fixation with better retained activity were studied by Ibrahim *et al.* (2007). Prolonging the reaction time from 5 to 30 min or raising the fixation temperature from 70 to 90°C results in gradual increase in the extent of immobilization irrespective of the used enzyme which is a direct consequence of enhancing the swettability of cellulose structure and availability of its reactive sites-COOH groups, as well as the mobility and activity of the used enzymes, thereby accelerating and improving the extent of the enzyme fixation.

Complex metallic compounds based on metals like cadmium, silver, copper and mercury cause inhibition of the active enzyme centres (inhibition of metabolism) of microorganisms. Amongst these, the silver compounds are very popular and already been used in the preparation of antimicrobial drinking water. Higazy *et al.* (2010a) reported that although both tannic acid and metal ions serve as antimicrobial agent, they are inactive towards several kinds of microorganisms. The technical feasibility of using tannic acid to form in situ complex with environmentally save metal ions onto jute cellulose was reported. Three kinds of metal salts were selected for complexation, namely, $AgNO_3$, $ZnSO_4$, Zr $(SO_4)_2$. $4H_2O$. Cellulose-tannic acid-metal complexes were formed in situ by treatment the jute fabric with tannic acid then allow the treated samples to absorb the metal ions from its aqueous metal salt solution. The effect of both tannic acid and metal salt concentration on the antimicrobial activity of the treated jute fabric as well as washing durability were investigated. Current data disclosed that jute fabrics treated with tannic acid-metal complex formed in situ show enhanced antimicrobial properties compared with those sample treated with tannic acid or metal ions separately and at the same concentrations. The results showed also that both antibacterial and antifungal properties of the jute fabric treated with tannic-metal complexes follow the order: tannic acid-Zn>tannic acid-Zr>tannic acid-Ag. It was found also that the washing durability of jute fabric treated with tannic acid-metal complex was very high and depends on the type of metal ion used in complexation and follows the order: tannic acid-Zn>tannic acid-Ag> tannic acid-Zr. Ibrahim *et al.* (2006) also reported that cotton fabric was ester cross-linked with citric acid (CA) in the presence of sodium hypophosphite (SHP) as a catalyst (80/80 g L^{-1}) then the pendant COOH groups of finished fabrics are utilized in binding metal salts. These treatments acquire the fabrics antimicrobial activity towards *B. subtilis*, *B. mycoides*, *S. aureus* (Gram +ve) and *E. coli* (Gram-ve). Generally zinc salts impart to the fabric the highest antimicrobial activity, followed by cupric acetate. Zinc chloride proves to be the metal salt that yields the maximum antimicrobial activity. When CA was replaced by pyromellitic anhydride (PAD), the antimicrobial activity of the post-treated fabric was higher in CA than in PAD. Partial replacement of CA/SHP by dimethylol dihydroxy ethelene urea (DMDHEU) results in slight decreasing in antimicrobial activity.

Chitosan coatings on conventional fibres appear to be the more realistic prospect since, they do not provoke an immunological response. Fibres made from chitosan are also available in the market place. In this connection, Higazy *et al.* (2010b) reported that scoured jute fabrics were treated with chitosan (pre-dissolved in 1% acetic acid) under a variety of conditions. The latter were included chitosan concentration, fixation temperature and time. The antimicrobial activity was evaluated using two kinds of microorganisms, namely, *Staphylococcus aureus* and *Candida albicans*. Treatment of jute fabrics with chitosan improves only the antibacterial properties towards *S. aureus* whereas, antifungal properties remain intact. A similar study was carried out using chitosan-etal

complex aiming to impart the jute fabric antimicrobial properties. In this regards, Ag^{1+}, Zn^{2+} and Zr^{2+} ions were allowed separately to form a complex with chitosan. It has been found that jute fabrics treated with chitosan-metal complex show better antimicrobial properties than those fabrics treated with either chitosan or metal salt separately. Moreover, the jute fabrics treated with chitosan-Zn complex have higher antimicrobial properties compared with those samples treated with chitosan-Zr or chitosan-Ag complexes.

FUTURE PROSPECTIVE

Nanotechnology treatment is the latest term covering a wide range of technologies, including protective treatment in textile finishing, concerned with structures and on the nanometer scale. The technology can be used in developing advanced performance characteristics, such as antimicrobial resistance, water repellency, fire retardancy, etc. in fibres, yarns and fabrics. Although, textile industry is a small part of the global research in the emerging areas of nanotechnology, the fibres and textiles industries in fact were the first to have successfully implemented these advances and demonstrated the applications of nanotechnology for consumer usage. Nonwoven fabrics composed of nanofibres have a large specific-surface area and small pore size as compared to commercial textiles making them excellent candidates for filter and membrane applications and consequently it is possible to fabricate mesh with varying degrees of fibre alignment.

In the future nanotechnology will play a more crucial role in the development of textiles market. With nanotechnologies, scientists will be able to produce particles small enough to be use effectively as plastics and polymer additives. This means that we will be able to produce plastics with different properties, with more efficient antimicrobial or fire retardant properties. The growth of nanotechnology markets will influence the whole additive markets, including antimicrobials (Qian and Hinestroza, 2004).

METHODS FOR TESTING ANTIMICROBIAL ACTIVITIES

The following are different test methods used for determining the effectiveness of antimicrobial treatments on textile products:

AATCC 30 (2004): Antifungal activity, assessment on textile materials: mildew and rot resistance of textile materials: The general purpose of this method is to determine the susceptibility of textile materials to mildew and rot and to evaluate the efficacy of fungicides on textile materials. Four tests were used:

Test I: Soil burial: This procedure is generally considered to be the most severe test for textile products. Only those specimens that will come in direct contact with soil, such as sandbags, tarpaulins, tents need to be tested by this procedure. The length of exposure to the soil bed and percent retained breaking strength when compared to the unexposed textile were then reported.

Test II: Agar plate, *Chaetomium globosum*: This procedure is used for evaluating rot resistance of cellulose-containing textile materials that will not come in contact with soil. It may also be used for determining uniformity of fungicide treatment. The change in breaking strength as compared to the sample before exposure or the control and the extent of fungal growth on the discs, using a microscope (50X) were determined by visual assessment.

Test III: Agar plate, *Aspergillus niger*: Certain fungi, including *Aspergillus niger*, can grow on textile products without causing measurable breaking strength loss within a laboratory experimental time frame. Nonetheless, their growth may produce undesirable and unsightly effects. This procedure is used to evaluate textile specimens where growth of these fungi is important. At the end of the incubation period, the percentage of surface area of the discs covered with the growth of *Aspergillus niger*, using a microscope (50X) was then estimated.

Test IV: Humidity jar, mixed spore suspension: This test method is designed to determine the fungistatic effectiveness of treatments intended to control mildew and non-pathogenic fungal growth on articles or surfaces composed of textile materials intended for outdoor and above ground use and which are usually waterproofed. A record of the percent of surface area covered with fungal growth for each strip is made at weekly intervals or until heavy growth occurs on each sample replicate, using a microscope (50X).

AATCC 100 (2004): Assessment of antibacterial finishes on textile materials: Assessment of antibacterial finishes on textile materials is determined by the degree of antibacterial activity intended in the use of such materials. If only bacteriostatic activity (inhibition of multiplication) is intended, a qualitative procedure which clearly demonstrates antibacterial activity as contrasted with lack of such activity by an untreated specimen may be acceptable. However, if bactericidal activity is intended or implied, quantitative evaluation is necessary and it can provides a clearer picture for possible uses of such treated textile materials.

AATCC 147 (2004): Antibacterial activity assessment of textile materials (Parallel streak method): The parallel streak method has filled the need for a relatively quick and easily executed qualitative method to determine antibacterial activity of diffusable antimicrobial agents on treated textile materials. AATCC Method 100, is a quantitative procedure which is adequately sensitive but is cumbersome and time consuming for routine quality control and screening tests. Therefore, when the intent is to demonstrate bacteriostatic activity by the diffusion of the antibacterial agent through agar, Method 147 fulfills this need. In the parallel streak method, the agar surface is inoculated making it easier to distinguish between the test organism and contaminant organisms which may be present on the unsterilized specimen. The parallel streak method has proven effective over a number of years of use in providing evidence of antibacterial activity against both Gram positive and Gram negative bacteria. The incubated plates for interruption of growth along the streaks of inoculum beneath the specimen and for a clear zone of inhibition beyond its edge was then measured.

AATCC test method 174-1998: Antimicrobial activity assessment of carpets: This test method is designed to determine the antimicrobial activity of new carpet materials and consists of three procedures (qualitative antibacterial; qualitative antifungal and quantitative antibacterial assessment). This test method may also be used to evaluate the effect of a cleaning process on the antimicrobial resistance of carpets. The incubated plates for interruption of growth, along the streak of inoculum beneath the specimen, for a clear zone of inhibition beyond the specimen edge and the width of the zone of inhibition around the test specimen, were then estimated.

ASTM E2149 (2001): Standard test: Method for determining the antimicrobial activity of immobilized antimicrobial agents under dynamic contact conditions: This test method is used for quantitatively determining the antimicrobial activity of immobilized antimicrobial agents under dynamic contact conditions. This dynamic shake flask test was developed to overcome difficulties in using classical test methods to evaluate substrate-bound antimicrobials (i.e., non-leaching antimicrobials). The activity of a substrate-bound antimicrobial is dependent upon direct contact of microbes with the active chemical agent. This test determines the antimicrobial activity of treated specimen by shaking samples of surface bound materials in a concentrated bacterial suspension for an hour contact time. The suspension is serially diluted both before and after contact and cultured. The number of viable organisms in the suspension is determined and the percent reduction in numbers is calculated based on initial counts or on retrievals from appropriate untreated controls. This method is intended for those surfaces having a percent reduction activity of 50 to 100% for the specified contact time.

METHODS FOR APPLYING ANTIMICROBIAL AGENTS

There are many options to weigh when considering which antimicrobial is best for a particular product. Application method is an important aspect to examine with more detail. There are three main options for applying an antimicrobial agent to textiles. Each has its own advantages and challenges. The first option is treating the fabric through an "aqueous process" in the finishing line with the antimicrobial substance. The second is incorporating the antimicrobial into or onto the fiber itself. A third application method, is post-consumer, an antimicrobial additive designed to be added to the laundering water each time the product is washed.

MODE OF ACTION OF ANTIMICROBIALS

The primary modes of action of antimicrobial agents against microorganisms are mainly due to their action as inhibitors for cell wall synthesis, cell membrane, protein synthesis, nucleic acid synthesis and competitive inhibitors. The bound unconventional antimicrobial technol-ogy, has a mode of action that relies on the technology remaining affixed to the fabrics. This shield technology does not dissipate or leach; it can not be absorbed by the microorganism or by the consumer. The membrane of the microbe is physically ruptured by a stabbing and electrocution action. Since it is not consumed and does not dissipate, the antimicrobial active is not depleted and continues to control microbial growth over time. This means that the antimicrobial will be fully effective as long as the surface remains intact. The followings describe some mode of actions of different antimicrobial agents:

Quaternary Ammonium Salts (QAS): QAS poses its activity on the outer cell membrane as well as on the inner cytoplasm membrane. It destroys the outer cell membrane at least of gram-negative bacteria. Firstly, QAS is absorbed and then it penetrates the outer cell membrane, then reacts with several components, e.g., lipids and proteins and produces a disorientation of the membrane. Further on, proteins and nucleic acid are degraded. Finally, this results in lyses of the cell wall (Gottenbos *et al*., 2002).

Metal ions: The action with microorganisms such as bacteria is known to be in the cell walls. Metal ions bind to free sulfur residues in enzymes that facilitate oxygen transfer through the bacterial cell membrane. By binding to these sulfur groups the enzyme is blocked from binding oxygen and

transporting it to the cell inside, hence the bacteria cannot undertake respiration and die. This specific binding to the oxygen carrying enzyme is augmented by the metals ability to bind to other proteins and enzymes within the microorganism and cause change in proteins shape and indeed crystallize hence, rendering them inactive, again causing cell death of the microorganism (Avery *et al*., 2004; Kumar *et al*., 2005).

Copper ions: The damage was caused by copper binding to the sulfhydryl-groups of respiratory enzymes in the cell membrane.

Silver ions: Silver ion reacts with the thiol-group in vital enzymes and inactivates them or interacts with DNA, resulting in marked enhancement of pyrimidine dimerization by photodynamic reaction and possible prevention of DNA replication. Structural changes in the cell envelope and the presence of some small electron-dense granules formed with silver and sulfur have also been demonstrated in bacterial cells. It is proposed that two possible successive processes may be involved in the action of silver. First, cells that contacted with silver take up silver ions which inhibit several functions in the cell and consequently damage the cells. The second, is the generation of reactive oxygen species which are produced possibly through the inhibition of a respiratory enzyme (s) by silver ions and attack the cell itself.

Zinc ions: Zinc ions bind to certain components in the cell wall of microorganisms and cut off the flow of oxygen into the cell. The cell cannot, therefore, carry out respiration, the process of using oxygen to create energy and the cell dies. This mode of action is inherently quick and is exclusive to the unicellular microorganisms. Zinc has extreme potency towards fungal infections along with a strong bioaction against bacteria and protozoa.

Chitosan: Different theories have been put forward to explain chitosan's antimicrobial mode of action. One theory indicates that there are significant electrostatic and hydrophobic interactions, as well as hydrogen bonds between lipids and chitosan. Related to this fact, chitosan being a lipid binder, might be able to extract lipids from the bacterial membrane. Many investigators indicated that the initial contact between the polycationic chitosan macromolecule and the negatively charged cell wall polymers is driven by electrostatic interactions and that teichoic acids play a major role, leading to a disruption of the cell wall equilibrium dynamics. Other investigators reported that binding of chitosan to cell wall polymers would then trigger secondary cellular effects: destabilization and subsequent disruption of bacterial membrane function occur, via unknown mechanisms, compromising the membrane barrier function and leading to leakage of cellular components without causing distinct pore formation. In addition, membrane-bound energy generation pathways are affected, probably due to impairment of the proper functional organization of the electron transport chain, thus interfering with proper oxygen reduction and forcing the cells to shift to anaerobic energy production. This might ultimately lead to dysfunction of the whole cellular apparatus. Also the accumulation of the polymer in the membrane vicinity triggers various stress responses due to a local low pH or other factors that remain to be identified. The complex mechanisms by which these processes are happened have not been fully ascertained. Future work should aim at clarifying the molecular details of the underlying mechanisms and their relevance to the antimicrobial activity of chitosan (Didenko *et al*., 2005; Je and Kim, 2006).

Enzymes: The effect of enzymes as antimicrobial agents is mainly due to the electrochemical mode of action to penetrate cell wall of microorganism, thereby causing leakage of essential metabolites and physically disrupting other key cell functions on contact to kill it and thoroughly leaching antimicrobial moieties to enter or react chemically with the microorganisms acting as a poison or inhibitor (Ibrahim *et al*., 2007). Chemical treatments can however, result in damage to the whole fiber which may adversely affect handle properties and release hazardous chemicals into the environment. The use of enzymes for wool surface modification is a possible solution to these problems and has attracted considerable interest in recent years (Nierstrasz and Warmoeskerken, 2003; Shumi *et al*., 2004). The majority of this research has been directed towards shrink-resist and softening treatments using proteolytic enzymes (Heine and Hocker, 1995) and relatively few studies have examined the use of esterases to hydrolyze ester- or thioester-bound fatty acids from the fiber surface.

The effect of protease/lipase enzyme pretreatment followed by polysiloxane based combination finishing on handle properties of wool: cotton union was studied by Ammayappan and Moses (2011). The results inferred that both enzymes improve the handle of the union fabric irrespective of their nature and subsequent combination finishing further improves the handle. The extent of improvement depends on the nature of finishing combination applied, in which combination of nano, micro, macro polysiloxane with a cationic softener on savinase treated fabric shows better hand value than others. These investigators were concluded that combination finish on savinase treated union fabric imparts better handle properties than corresponding Lipolase treated ones and finished-only fabrics. In another study, Shridhar *et al*. (1995) improved the softness of wool: cotton blended fabric by treating them with cellulase enzyme successively with protease enzyme with favorable changes in the physical and handle properties.

CONCLUSION

From the study the following conclusion can be made:

- Imparting antimicrobial permanent finishes to different textiles would help to prevent microbial attack and to obtain aesthetic and hygienic functions
- The bound unconventional antimicrobial technologies (non-leaching finishes) were found to be the most effective methods for application onto textiles, as they do not leach or diminish over time
- Quaternary ammonium salts, metallic salts, chitosan, enzymes and nano-technological compounds were the most durable and effective type of antimicrobial agents applied to the fabrics
- The quantitative dynamic shake flask test was developed for routine quality control and screening tests in order to overcome difficulties in using other classical antimicrobial test methods
- Different mode of actions was described for different antimicrobial agents. The most confirmed one is summarized in binding to the sulfur groups in the active site of microbial enzyme which is blocked from binding oxygen and transporting inside the cell

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