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Antimicrobial finishes for Textiles

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Abstract

Infestations by micro-organism instigate cross disease by pathogens and odor develops in fabric have direct contact with the skin. Moreover, discoloration, tints and loss of functional characteristics of textiles are consequence of microbial damage. Antibacterial finished textile is an important area for medical and hygienic applications and there is enormous need of non-toxic and eco-friendly antimicrobial agents. The synthetic biocides finishes extensively reported were polyhexamethylenebiguanide (PHMB), quaternary ammonium compounds (QACs), metals (including metal oxides and salts), triclosan and n-halamines. Whereas, the natural based biocides (aromatic compounds, dyes, essential oil), chitosan and antimicrobial peptides (AMPs) were mainly considered among plant-based extracts. This paper will cover briefly, review of the latest research work on antimicrobial finishing, types of finish agents and various current developments in antimicrobial finishing to minimize the risks associated with application of organic, inorganic and plant based antimicrobial finishes.

Keywords: Antimicrobial; Organic and inorganic finishes; Life; Textiles

Introduction

The major use of the antimicrobial was in the medical and the pharmaceutical industry. However, newer applications are possible. The textile fibers are these days increasingly treated with antimicrobial reagents. The other examples include the applications in food packaging and food storage, and medical, surgery and hygienic products etc. [1-3]. With the improvement of life standards, the demand of hygienic products is increasing for biocidal finishes in textiles (sports-wears, undergarment, bed-linen) and water filtration. The antibacterial finish treatment has become vital area of medical, surgical and healthcare activities due potential pathogenic microorganisms present in hospital environment and cause cross-infection diseases [4-8]. The types of micro-organisms include different kinds of organisms such as virus, bacteria, unicellular plants and animals, certain algae and fungi. Classification in bacteria family is “gram positive, gram negative, spore bearing or non-spore bearing type”. Some of the bacteria are of pathogenic nature that may cause infections to human [9]. A microbe (e.g. bacteria and fungus) normally protected with an outer cell wall that is composed of polysaccharides. The cell wall keeps up the veracity of cellular components and protects the cell from the extracellular situation; below the cell wall is a semi-permeable membrane that holds intracellular organelles, enzymes and nucleic acids. Chemical reactions within cell wall take place due to the enzymes present in cell wall. The nucleic acids hold the entire genetic directory of organisms [10]. The microorganisms responsible for microbial damage are generally present in surroundings; besides, formation of the substrates and the chemical processes may encourage growth of the microbes; further moist and warm environment still exaggerate the problem [11]. A gram-positive bacterium contains peptidoglycan and teichoic acid, peptidoglycan comprises of 90% of cell walls and made of amino acid and sugar. One example of gram-positive bacteria is Staphylococcus aureus that is in form of pair, short chain or graphic like cluster. Its size range is 0.5µm to 1.0µm and grows in temperature range of 35 to 40 °C.

Staphylococcus aureus is major cause of cross infection in hospital environment and 19% of total surgical infection. It’s also responsible for boils and also cause scaled skin infections. Other gram-positive bacteria are Staphylococcus epidermidis, Streptococcus pneumonia, Streptococcus pyogenes and Steptococcus viridians. The gram-negative bacteria are alike to gram positive bacteria apart from an outer layer of membrane affixed to peptidoglycan by lipoproteins which used to transport too low molecular weight substances. Gram negative bacteria are firm to diminish has compare to gram positive bacteria for the reason that of extra cell walls. An example of gram-negative bacteria is Escherichia coli (E. coli); its shape is similar to a bacillus and dwell in intestine of human. Escherichia coli can be proliferated during eating and/or usage of raw food stuff. The indications of E. coli are result in rigorous diarrhea (especially in kids) and kidney destruction. Other bacteria of this class are Klebsieella pneumonia, Pseudomonas aeruginosa, Salmonella typhi, Salmonella enteritidis and Haemophilusinfluenzae etc. [12]. Infestations by micro-organism instigate cross disease by pathogens and odor develops in fabrics that are worn after to skin or having direct contact with the body mass. Moreover, discoloration, tints and loss of functional characteristics of textiles are consequence of microbial damage [13-17]. Fungi moth or mildews are organism with lower progress ion rate; they stained the substrate and damage the fabric functional characteristics. Algae are classic microbes that either be fungi or bacteria, generate darker stains on the fabric surface [18]. Dust mites' dwell in the home textiles and bed linen items include blankets, bed sheet, pillows and; especially in mattress and carpets. The dust mites feed on human skin and causes allergic reaction by healing waste products.

Antimicrobial Finishing Process

"The antimicrobial finishing process imparts the ability, to textile substrate, to inhibit the growth (-static) or reproduction of at least some types of microorganisms or to kill (-cidal) at least some types of microorganisms" [19,20]. Therefore, an antimicrobial finish should be capable to kill the microbes by breaching the cell wall or alter cell membrane permeability, obstructing the synthesis of proteins of microbes, blocking enzyme production necessary for microbes' food. A few established antimicrobial agents, e.g. silver, quaternary ammonium compounds (QAC), N-Halamines; triclosan [21-28] and polyhexamethylenebiguanide (PHMB) all are almost biocides [29-31].

Finishing Mechanism

Three finishing mechanisms may be recognized based on the antimicrobial function performed by the particular finish on the textile. These mechanisms include control-release, regeneration and barrier-block. The first two finishing mechanism having problems in usage.

The problems with control release mechanism are its durability after laundering and leaching of antimicrobial agent from fabric which can come in contact with wearer's skin. These agents have the potential to affect the normal skin, which could lead to extreme skin irritation and allergy issues. These problems can occur with the fabric using a regenerate mechanism as these agents require chlorine bleach to activate its antimicrobial properties after laundering. Chlorine bleach not only damages the cotton fabric but is also harmful for human skin. Barrier- block mechanism does not pose the problems associated with other two methods. These agents are bonded on fabric surface and do not leach, thereby killing the bacteria that come in contact with the fabric [32].

Classification of Antimicrobial Finishing Process

The antimicrobial finish can be applied by physical and chemical methods, and by adding functional agents on to textile fibers. Such functional finishes can be of two main types, i.e. temporary antimicrobial finish and durable antimicrobial finish. The temporary finishes may lose easily while come into contact with skin or body fluids or during washing process because of weak bonding of finishing agent with fibers surface. Durable finish can generally be achieved by adding an antimicrobial finishing agent into fiber or textiles in wet processing, this method also known as controlled release mechanism. In such treatment, the finishing agent itself bonded with the fiber surface or a bonding substance may be used. The treated textiles deactivate bacteria by slowly releasing the biocide from the fiber or fabric surface [32].

Types of Antimicrobial Finish

A variety of chemical agents are available that may impart significant effect in textile fibers to inhibit the growth of microorganism. The important types of antimicrobial chemical agents are described in the following sections

Organic antimicrobial agents

Organic antimicrobial agents such as quaternary ammonium compounds (QACs),N-Halamines, Polyhexamethylene Biguanide; triclosan,; silicon based quaternary agent [33]; iodohors, phenols and thiophenols, heterocyclics, inorganic salts, nitro compound, urea, amines and formaldehyde derivatives, have been applied for antimicrobial treatment of textiles [34].QACs have been tested for antimicrobial activity of protein base wool, cellulose base cotton, synthetic base polyamides and polyester, the MIC value 10-100mg/l presented good reproducibility and good washing durability. These formations kill the microbes by altering cell membrane permeability, obstructing the synthesis of proteins of microbes, blocking enzyme production necessary for microbes' food. The N-halamine compound is used for the development of antimicrobial cotton fabric through pad-dry-cure process followed by the exposure to chlorine bleach. The chlorinated sample showed potential antimicrobial ability against gram +ve and Gram –ve pathogens. It was experimented that on chlorinated after 15 days storage 85% of chlorine could be recharged that shows N-halamine compounds have good biocidal efficiency for healthcare textiles. Another organic based antimicrobial agent, Triclosan has been investigated for its antimicrobial ability for polyester, nylon, regenerated cellulose and acrylic fibers; with MIC value below than 10ppm versus bacteria against. Triclosan has excellent durability after use/washing and it prevents microbial growth by obstructing lipid biosynthesis. The most acceptable organic agent used for healthcare procedures, pharmaceutical and food industry is

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Poly-hexamethylene biguinide (PHMB). It's efficient against both types of bacteria, in addition to yeasts and fungi. PHMB is slightly toxic and fewer skin infection issues were reported. It used in variety of products including undergarment and towel fabric to obstruct microbial growth and exhibited good washing durability. PHMB is bacterio-static at 1-10mg/l but at elevated values its bactericidal activity and inhibition rate raise collectively. The utmost antibacterial inhibition action of PHMB obtained between 5-6pH value [35,36].

Inorganic antimicrobial agents

The inorganic finishing agents such as metal oxides, copper and zinc, titanium, magnesium, silver and gold were applied for antimicrobial effects on textiles. These agents exhibited good durability for cellulose, protein, regenerated and synthetic materials with MIC value 0.05-0.1mg/lversus gram negative bacteria, E.coli. Sliver is wide acceptable inorganic antimicrobial agent and kills microorganisms by blocking and disengages the intracellular proteins. However, silver is a slight toxicagent, it releases slowly and can worn-out of the fabric [37-40].

Zeolites of chabazite-type with its optimal morphology and lowest silicon to aluminum ratio (Si/Al)solution that replaced with different combinations of silver, copper, and zinc ions to prepare single, binary, and ternary metal cation-modified zeolites were experimented and silver based zeolites exhibited more antimicrobial activity than the others and demonstrated good/suitable mechanical characters and excellent biocide effect against food borne bacteria and fungi on green polyethylene developed based on injection-molded composite. Further, the result confirmed its capability to rule the propagation of dangerous pathogens in environment of food processing and storage. Thus, these innovative antimicrobial materials are prospects for hygiene surfaces, kitchen accessories and packaging applications [41].

Limitations of inorganic and organic agents

In general, antibacterial property of any inorganic finishing agent is established with its chemical components. The biocide efficiency of inorganic agents slowly drops in use and during wash. The most of such agents carry limited intensity of microbes' inhibition, moreover they are poisonous, initiate skin problem to humans and having problem to decompose in down streaming [42,43]. To reduce the risks allied with the application such inorganic agents, there is enormous need of substitute agents for antimicrobial treatment of textiles. As mentioned early, a wide range of organic antimicrobial agents are available for textiles treatment but out of these agents; triclosan, quaternary ammonium compounds, Polyhexamethylene Biguanide have been used on commercial scale. Polyhexamethylene Biguanide is slightly contaminated with poisonous concerns and hard to decompose in down streaming. In US Preregistration Eligibility Decision for PHMB by US Environment Protection Agency" the discharge of effluents containing PHMB is not allowed without mandatory treatment.

Eco-Friendly Antimicrobial Agents (Natural Plant and Fruit Extracts)

Plant extracts provided an attractive source of eco- friendly antimicrobial finish. The natural cure using plant extracts is increasingly receiving interest in the development of antimicrobial textiles. One of the plant-based sources is belong to Meliaceae family Neem (Azadirachtaindica); it is one of the most prominent from natural gifted sources of antimicrobial compound. All parts of neem are established for potential antimicrobial constituents. The extract from each part of the neem presented active antimicrobial effectiveness to block the proliferation of the bacteria. Currently, a small number of studies has demonstrated neem' used for textiles to evaluate it antimicrobial activity. However, cotton and cotton/polyester blended fabric treatment with seed and bark extracts were reported [44-46]. Moreover, the cotton fabric imparted with neem leaf extract loaded nanoparticle [47]and synthesis of sliver nano-particles using extract of neem leaf for cotton treatment was also used [48]. Another plant-based source belongs to the Liliaceae family Aloevera (Aloe barbadensis), its leaf extract has antibacterial and antifungal potential and have been used for dressing gauzes, sutures and other medical textile applications [49,50]. Similar to neem applications in textiles, a few studies of aleovera application for cotton fabric treatment were articulated. However, more research is required. Antimicrobial finishing of cotton and cellulose fibers is significantly useful and important in medical textiles utilization [51]. One of the other plant-based sources is Ginkgo biloba or Ginkgoceae (Mantissa Plantarum Altera). Ginkgo biloba tree has flourished in jungles for more than 150-250 million years. It is assumed to be one of the aged living species on earth [52-54]. The standardized extract formulation of ginkgo leaf in used hold "5-7% ginkgolides and bilobalide (BB) [55]". It is an excellent candidate for antimicrobial treatment of healthcare cotton textiles. The formulation of Ginkgo biloba extract standard values were forced because cyto-toxicity issues was reported beyond these limits [56-58]. Jang and Lee investigated ginkgo leaf extract antimicrobial activity for Tencel fabric in extract formulation containing silicon softer along with crosslinking agent.

The study concluded that Ginkgo Biloba extract is eco-friendly antimicrobial agent and their application was investigated in health and medicinal purposes. It is exclusively for non-toxicity characteristics linked with such other agents, it is potential candidate for antimicrobial finishing of institutional textiles range including home accessories and hospital bed sheet, nurses' uniforms, surgical gown and drapes etc. [59]. The plant based natural fruit source reported for antimicrobial properties, the fruit-based source is Pineapple (Ananascomosus) juice was investigated against harmful microbes60. The antimicrobial activity was evaluated through agar diffusion method. Another plant base source reported is Papaya (Carica papaya). Its fleshy tissues hold three influential antioxidants i.e., vitamin A, C and E. Further, it contains stuff of proteolytic enzymes that have

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good antimicrobial activity against bacteria, fungi and virus. The papaya fruit seeds are spicy and very strong that yield them almost indigestible. These seeds have more potential pharmaceutical worth as compare to it's the flesh and are effective against bacterial infection. The juice presented the excellent antimicrobial ability versus a number of gram native bacteria [60-63]. Moreover, the uses of both these fruit juices/ extracts were not reported to assess their biocide or bio-static activity.

The medicinal plants Clove (Eugenia caryophyllata), Falsedaisy (Eclipta alba), Leadwort (Plumbagozeylanica), and Mint (Mentha Arvenesis) parts were dried, powdered, grinded and extracted with solvents and applied through pad-dry-cure and microencapsulation techniques. The fabric samples were then subjected to antimicrobial testing and the bacterial growth was analyzed after 5, 10, 15 and 20 washing cycles. The antimicrobial activity of microencapsulated finish was effective till 15 wash cycles64. Several other plant base dyes are reported for their antimicrobial and antifungal activity such as Henna (Lawsoniainermis), Walnut and alkanet (Anchusa Tinctoria), curcumin, pomegranate, cutch, red onion peel and a mixture of red onion peel/curcumin (40 g/L, 50%)65. The extract of neem (Azadirachataindica), Lam (Buteamonosperma) and Gaetin (Litchi chinensis) trees was used to check antibacterial, antifungal activity and aesthetic properties (stiffness and appearance) of 100% silk fabric. It was confirmed that the formulation of antimicrobial finish improves the aesthetic properties. It is further reported that treated finished showed good/suitable/optimize results and 89% reduction in microbial growth was achieved up to 25 washes66. Application of the plant base dye-stuff is the art of imparting hues and tints to textile substrate. Dye-stuff or coloring matters acquired from natural resource are tested for antibacterial activity of the fabrics and results of the dyed fabrics presented these days have effective antibacterial activity. Although, synthetic dyes contain a range of vibrant color and are extensively used but now a day, natural dyes gaining interest because of strict environmental standard forced by a number of European states due to carcinogenicity and photosynthetic issues of synthetic dyes. Natural dyes are considered as eco-friendly, nontoxic, medicinal features [67]. The essential oil extracted from Rosemary (Rosmarinusofficinalis) and orange (Citrus sinensis) were obtained by steam distillation from rosemary vegetal mater and orange peel used to evaluate the antimicrobial activity for textile substrate (56% cotton/44% polyester) with concentration of 1%, 3% and 5%of each oil and antimicrobial activity was assessed against each strain. The demonstrated results support textiles functionalized with rosemary and orange essential oils, both are efficient active antimicrobial barriers with maximum reduction of 56.99% for rosemary and 92.48% reduction for orange essential oil [68].

Plant based Bamboo material is well known for their antimicrobial ability. In presented reported study focused to evaluate the antimicrobial property of plasma treated bamboo fabric imparted with combinatorial herbal extract. The knitted bamboo fabrics were rendered to plasma treatment at most appropriate setting to improve the hydrophilicity. The variations in the hydrophilic characteristics, physical and chemical changes of the plasma treated fabric were measured by using standard tests and combinatorial herbal powder was subjected to different solventextracts and their antimicrobial efficiency against pathogens were evaluated. The ethanol herbal extract presented higher antimicrobial activity against E. coli (12mm), S. aureus (14mm) for zone of inhibition and tests proved wash durability retained till 25 washes [69,70].

The chitosan and alginate have been used for antimicrobial finishing of textiles. Chitosan is derivate of chitin, water-soluble cellulose based. Chitin is a polysaccharide base on amino sugars. In an acid solvent amine component turn into quarterly amino unit that inhibits growth of microbes. Theses amino unit performs as shield to block protein and slow down proliferation by distracting cell membrane; this permit the substance to escape from bacterial cell, consequential results is death of the bacteria. Antimicrobial activity of chitosan was reported in many studies and it is widely accepted antimicrobial agent [71]. The β-Cyclodextrin, Chitosan citrate and β-Cyclodextrin/Grafted Chitosan with lavender essential oil were also used to evaluate the combined effect of fragrance and antimicrobial activity on cotton textiles through pad-dry method. The results discovered that β-CD was highly soluble in 0.6g/l NaOH solution and 80 gpl β-CD and 6% essential lavender oil solutions were found to be a most suitable combination for fragrance and antimicrobial property [72]. In another study, the most common polymers polypyrrole (PPy) was used with its environmental stability, ease of synthesis, exciting chemical, electrical, electrochemical and optical properties [73]. The antimicrobial activity of polypyrrole-graft-chitosan copolymer was investigated by chemically synthesized, and then its composition and morphological characteristics were evaluated. The results discovered the strong interactions among polypyrrole and chitosan chains. Further, the electrical conductivity of chitosan increased to semi-conducting level by grafting. The thermal stability and crystallinity of polypyrrole-graft-chitosan copolymer increased while compared to chitosan. The copolymer was evaluated versus various bacterial and fungal strains at different concentrations and results achieved were evaluated with the reference antibiotics and it was pointed that the polypyrrole-graft-chitosan copolymer has stronger antibacterial activity than the polypyrrole and the chitosan alone; and it further increased at higher concentrations [74]. Monica Periolatto reported, the sound fastness and stability was attained with both photo-grafted chitosan and polypyrrole coating on textiles. It was proposed that a synergic impression of polypyrrole-chitosan finish, exploitable in textiles [75].

Challenges Associated with Plant Finishes

The chitosan is one of the recognized bioactive agents used on commercial scale for fabric antimicrobial finishing.

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On the other hand, its effectiveness is spoiled by a few factors. It depends on the chitosan molecular weight, pH value, ions intensity, add-on of non-aqueous solvents and the grade of deacetylation. Moreover, their treatments for textiles are efficient at maximum concentrations consequently reduce the air permeability of fabric and impart stiffness. Normally, herbal extracts including chitosan evaluated for their antimicrobial activity for textiles reported various issues, such as problem in extraction, separation of bioactive substances, textiles treatment with bioactive agents and the most important concern is poor finish durability after uses and during washing. Regardless of few most important challenges linked with plant based antimicrobial finishes, nevertheless these extract formulations are appealing with their non-toxic and environment friendly characteristics [76,77].

Role of Nanotechnology in Antimicrobial Finishing

Nanotechnology may provide finishes to combat infectious pathogens. Their application through nanotechnology engaged several parameters that control, manipulate and assemble nanoscale constituents to develop materials, systems or devices. Studies reported that the silver nano-particles exhibit excellent antimicrobial property versus microorganisms. For examples, the expedient use of antimicrobial metals such as zinc, copper and silver were incorporated into an FDA-approved polymer (polycaprolactone– PCL) to produce filaments. Hot melt extrusion was used to extrude pellets obtained by vacuum-drying of solutions of PCL and the different metals in order to manufacture metal-homogeneously-loaded filaments. Wound dressings with different shapes were produced with the filaments containing different concentrations of metals. The antibacterial efficacy of the wound dressings was tested using a thermal activity monitor system, revealing that silver and copper wound dressings had the most potent bactericidal properties [78].

Now a day, metal oxide nanoparticles (MeO-NPs) become a potential substitution to combat toxic infectious complaints and substantially resistant to different types of antibiotics [79]. ZnO particles nano-structured use on the cotton textile surface with different surfactants to stabilize, homogenize the coating and has improved the durability of ZnO NPs with decreased its leaching and showed the highest antibacterial and antifungal activities against different pathogenic bacterial and fungal species with high reduction reached over 90% [80]. Another technique used to investigate the antimicrobial property, i.e. application of Znonano-particle and use soluble starch as capping agents revealed that antimicrobial activity is oversee by the type of capping agents and results in achieved lower particle size of 3-5nm and higher antimicrobial rate as compared to other capping agents [81].

The use of Copper nano particle/nano-composite for antimicrobial ability in glycerol-polyvinyl alcohol matrix in gel and moldable plastic form proves that it can be produced and easily figured at high temperature. The materials show very good long-term stability in air, protecting the produced copper nano-particles from oxidation and proven inhibition of bacterial proliferation of both Escherichia coli and Enterococcus faecalis bacteria in nano-composite existence [82]. Biocompatible nanogold (AuNPs) have gained considerable attention for potential applications in nano-medicine due to their characteristic size dependent chemical, electronic and optical properties and displayed antibacterial efficacy towards different bacterial species and the MIC was evaluated to be 960μL/ml against S. aureus [83].

To overcome the toxicity and washing durability problems associated with plant-based extracts, application of chitosan-neem nano composites for development of antimicrobial cotton was used. Silver nanoparticles micro-gel based on poly-(N-isopropylacrylamide) and chitosan [84]; and chitosan nanoparticles loaded with Fe^{2+} or Fe^{3+} surfactant-assisted chitosan chelating Fe^{2+}, Fe^{3+} and ionic gelation chitosan showed very high antimicrobial property at lower concentrations as compared to chitosan [85]. In another study, the results confirmed the biosynthesized AgNPsusing pre-hydrolysis liquor of Eucalyptus wood as effective growth inhibitors against microbes for various biomedical applications [86]. Further, Chitosan and acrylic acid bi-grafted polypropylene melt-blown nonwoven membrane immobilized with silver nanoparticles presented excellent antibacterial and hydrophilic properties [87].

Conclusion

An interesting variety of antimicrobial finishing agents is available. However, limitations are possible to provide acceptable performance, environment-friendly traits, and cost requirements. Majority of inorganic antimicrobial agents are poisonous, potential problem to degrade in environment, inhibited a limited range of microbes and possess poor laundering durability; but comparatively organic agents have lower adverse effects. The use of nano-particle has improved the efficiency of some of the present use antimicrobial agents and reduced the environmental issues associated with these agents (such as toxicity and washing durability) and exhibit excellent antimicrobial property versus microorganisms. Moreover, despite the washing durability challenge associated with natural plants based antimicrobial finishes; they are widely accepted antimicrobial agents for textiles finishing with their eco-friendly and non-toxic characteristics. Use of plant based nano-particle antimicrobial agents has been growing in many different fields primarily due to their advanced characteristics and protection against pathogens as comparison to conventionally used biocides and such value-added finishes may provide sustainable healthcare applications in textiles.

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