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Photografted Chitosan as Antibacterial Agent for Textiles

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Abstract

The natural biopolymer chitosan was applied to textile substrates by ultraviolet photo grafting to confer antibacterial activity against a wide range of microorganisms. In this way an efficient and solid textile finishing was ensured by a low environmental impact process. The use of an environmentally friendly product is thus coupled to the adoption of an eco-sustainable process, that can guarantee the protection of both health and environment and produce fabrics complying with current regulations. Fabrics treated in this way can find application in all cases where it is necessary to counteract the proliferation of bacteria: medical devices, hospital and hygienic textiles, technical and furniture fabrics, but also in the field of water purification, as active biological filters.

Keywords: Chitosan; Antibacterial agent; Textiles; Cotton; UV-grafting; Water purification; *Escherichia coli; Staphylococcus aureus; Klebsiella*

Introduction

In last decades, globalization and even more stringent ecological regulations push textile companies to search for product quality improvements by environmentally friendly processes. Among targets, the use of processes with low water and energy consumption and the replacement of polluting or toxic chemicals with others of natural origin, with low or no environmental impact, are prominent. Furthermore, the frequent spread of diseases and infections highlights the importance of health and hygiene, promoting the production of antibacterial fabrics not only to avoid the degradation of the fabrics themselves, but also to effectively prevent the propagation of pathogens.

Fibers and fabrics of natural origin, hydrophilic and biodegradable, provide an optimal and favorable environment for the growth and proliferation of bacterial colonies; therefore, an antibacterial finishing, through appropriate chemical modification of the fibers surface, is particularly useful on these textiles. Metal ions (Ag+), quaternary ammonium salts, phosphonium salts or Triclosan are the chemical biocides commonly used today, but they were proved to be toxic or carcinogenic, so application on textiles, especially if in direct contact with the human skin, is not recommended considering the possible release of the antibacterial agent during use.

Biopolymers with intrinsic antibacterial activity, of natural origin from renewable sources, applied by an economic and ecological finishing process, is an interesting alternative for the development of bioactive textiles by eco-sustainable treatments. The proposed solution focuses on the finishing of textile fabrics by chitosan, grafted on fibers by photocuring [1]. Moreover, the application of a chitosan treated gauze for water filtration was also studied, aimed to disinfection and elimination of the same pathogenic microorganisms [2]. Water sanitation is an important issue worldwide: every year, more than 3 million people die in the world from diseases related to unhealthy water, responsible for 88% of diarrhea cases. The study has therefore a high application potential, with positive impacts in both scientific and socio-economic fields.

Chitosan UV grafting

Chitosan is a natural biopolymer mainly obtained from the exoskeleton of crustaceans. It is an abundant, low-cost by-product of the food industry, with well-known antibacterial properties against both Gram positive and negative bacteria, due to its combined bactericidal and bacteriostatic action, against fungi and viruses. Chitosan has no toxicity, and it is not a strong oxidant, avoiding the release of dangerous by-products during use; moreover, it is inert in water. For all these reasons chitosan can be considered as a sustainable alternative to other antimicrobial agents. Chitosan is already used in some textile finishing, applied by wet thermal curing with energy consumption, costs, and possible fabric degradation. Moreover, the addition of toxic reagents, such as glutaraldehyde [3], or expensive, such as genipin, is required as crosslinking agents to impart the required durability to repeated washings [4].

Therefore UV-curing of chitosan on fibers to confer antimicrobial activity was proposed as an alternative process to thermal curing or chemical crosslinking, obtaining a good effectiveness and fastness of the treatment. In UV-curing, radical species are generated by the interaction of UV light with a suitable photo initiator, which induces grafting reactions of reactive monomers and oligomers at low temperature and quickly, avoiding the emission of VOC, with lower environmental impact and lower cost than thermal process. Both chitosan and fibers, mainly cellulosic fibers, take part to this photochemical process. If a chitosan and initiator mixture is adsorbed onto the fibers and subsequently UV-cured, the polymeric chains can form inside the textile structure, which can also establish graft bonds, making the treatment solid and resistant. Moreover, the interpenetration of components and homogeneous distribution of monomers, even at a low concentration, contribute to obtain textile materials with modified surface properties, without high polymer add-on [5]. Consequently, the fabrics may retain their original properties of hand and breathability. Finally, the technology is easily implemented in the textile supply chain.

Chitosan as antibacterial finishing for textiles

Chitosan was applied by photograflting to several natural and synthetic fabrics, namely cotton, silk [5], wool [6], polyester and polyamide. The process was optimized, in terms of polymer add-on, ultraviolet exposure, impregnation and drying modality. The antimicrobial activity of treated samples was tested against Escherichia Coli, Staphylococcus Aureus and Klebsiella pneumonia, and compared with same samples treated by a commercial antibacterial agent based on Triclosan and quaternary ammonium salts.

The study confirmed the efficiency of chitosan against the tested bacteria and an excellent solidity of the treatment. A process yields equal to 100% was obtained on cotton and silk, while the hand and color of the treated fabrics were unaffected up to 2% add-on. However, the bacterial colonies were totally removed on fabrics treated with chitosan add-ons equal to just 0.3% owf, a very low amount unaffecting the peculiar properties of natural fibers. This strong antibacterial activity was unchanged after 30cycles washing, confirming the fastness of the treatment and the effectiveness of ultraviolet radiation to form strong radical bonds between chitosan and fibers.

The comparative test with the commercial product showed that it was less performing than chitosan, since after 30 washing cycles the antibacterial activity decreased to 98%, due to a certain release or inactivation of the antibacterial agent by surfactant action, while chitosan treated fabrics keep 99,999% of colony reduction [7]. Similar results were obtained, in terms of antibacterial activity, also on wool and synthetic fibers, but in this case a surface pretreatment was required to increase hydrophilicity and promote the absorption of the chitosan solution, due to hydrophobicity of this kind of fibers [6].

Chitosan for water purification

Water filtration tests were carried out on a cotton gauze treated with chitosan. The process for chitosan grafting was the same as for fabrics, but the add-on was increased till 25% owf. The as treated gauze was tested for continuous filtration of water contaminated by Escherichia, Staphylococcus or Klebsiella. The functionalized gauzes were tested in dynamic conditions, with bacteria inoculum continuously flowed through the filter several times. Results showed that a contact time, between the gauze and the contaminated water, of 4seconds was enough for the total elimination of Escherichia and Staphylococcus from the water, while after 8sec the Klebsiella was reduced by 98%. It is highly interesting since this fast speed of action guarantees total disinfection with a rapid flow of water, making the chitosan treated gauze an excellent candidate as biological filter.

The comparison was made in this case with a cationized cotton gauze, but the material was not suitable for filtration, reaching only 40% of bacterial reduction after a contact time of 20 seconds [2]. Considering water treatments, it is noteworthy that in previous studies the same chitosan treated gauze was found active also against other water pollutants: for the capture of heavy metals, like copper or chrome, present in water [8], and for sequestration of dyes from textile dyeing wastewaters [9].

Conclusion

Chitosan UV-grafting on both natural and synthetic fibers yields strong antimicrobial properties against different classes of microorganisms. The coupling of a natural, biocompatible, and renewable biopolymer with an ecofriendly photo grafting process makes it competitive and interesting versus the traditional toxic antibacterial agents applied by thermal processes, energy and water consuming. Therefore, the possibility to replace the established antibacterial finishing processes, based on hard and energy demanding chemical treatments, with an ecofriendly low temperature process using ultraviolet light and a natural and safe biopolymer such as chitosan, is undoubtedly an interesting result which can contribute to change the production of antibacterial fabrics toward a sustainable development.

It was confirmed by a semi-industrial scale-up and a deep cost analysis of the whole process. On the other hand, chitosan shows

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also promising applications in the field of water purification. In fact, it can totally remove pathogenic microorganisms from contaminated water in few times, allowing the continuous treatment of great amount of water with a little amount of filtering material. Some literature [10] suggests that chitosan and its derivatives can also suppress viral infections in various biological systems. However, the mechanism of this antiviral activity is poorly understood. Future studies could be focused on the investigation about antiviral properties conferred to textiles treated by chitosan photo grafting. If it will be confirmed, the potentialities for chitosan applications would be even more interesting.

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