SINGLE-STEP ANTIMICROBIAL AND MOISTURE MANAGEMENT FINISHING OF PC FABRIC USING ZnO NANOPARTICLES

Munir Ashraf1, Muhammad Irfan Siyal1, Ahsan Nazir2, Abdur Rehman3

1Department of Textile Processing, National Textile University, Pakistan. (email: munir.ashraf01@gmail.com, irfan.tex@gmail.com)
2Laboratoire de Physique et Mécanique Textiles, École Nationale Supérieure D'Ingénieur Sud Alsace, University de Haute Alsace, France. (email: ahsan.nazir@uha.fr)
3Department of Textile Processing, National Textile University, Pakistan (email: rehmansharif@hotmail.com)

Abstract:

Functionalization of textile fabrics with metal oxide nanoparticles can be used to add antibacterial and moisture management properties to them. Current work focuses on the development of these properties on polyester/cotton woven fabrics by treating them with zinc oxide nanoparticles for workwear and sportswear applications. Zinc oxide nanoparticles, prepared by sol–gel method, were applied on fabric samples, which were then tested for antibacterial and moisture management properties using standard test methods AATCC 147 with Staphylococcus aureus and AATCC 195, respectively. It was found that application of ZnO nanoparticles improved both these properties with smaller particle imparting larger effects on both of them.

Keywords:
Antimicrobial, Moisture management, Zinc Oxide, Nanoparticles

1. Introduction

Strenuous physical activity leads to the production of sweat by human body in order to manage the heat produced by it. This sweat provides favorable environment for the growth of odor-producing bacteria and other pathogens. Many research studies focused on the development of antimicrobial coatings for textiles. Textiles can be rendered “antifouling” properties by making them hydrophobic (i.e., lowering their surface energy in range of 20–30 mJ/m²) or by developing negative charge on them, which repels the negatively charged bacteria. Such treatments inhibit the bacterial growth on fabric surface by preventing bacteria from getting attached to textile surface and form biofilm [1, 2]. However, such hydrophobic textiles are not suitable to be used in active wear. Control of bacterial growth has also been achieved by treating textiles with certain agents that kill the bacteria on or nearby the fabric surface. Such “biocidal” surfaces can be either “contact-active biocidal,” if they kill the bacteria only when it comes in contact with fabric or “biocidal-releasing surfaces,” if the bacteria nearby the fabric surface also gets killed by the action of biocidal agent leaching from fabric surface [3]. The contact-active biocidal textiles have been produced by treating them with quaternary ammonium compounds, N-hexylmethylpolyethyleneimine, and derivatives of chitosan [3-5]. The biocidal-releasing textiles may be achieved by incorporating silver or zinc ions in them, which are continuously released to kill the bacteria around [6]. A similar treatment can also be achieved by incorporating semiconductors such as ZnO and TiO₂ into fabric assembly. They offer an additional advantage of catalytic release, that is, the biocide can be released, by exposure to UV light, when needed [5, 7-10].

Bacterial growth can also be reduced by eliminating their growth media, that is, the sweat produced by body. This also improves the overall thermophysiological comfort. The management of sweat using fabric assembly as an active medium has also been researched by many scientists, as improved moisture management not only improves the comfort properties of fabric but also removes away the medium (sweat) that bacteria need for their growth [11, 12]. A fabric’s composition and structure are among the most important properties that determine its capability to manage the sweat produced by the body [13]. Moisture management capability of profiled polyester blended with cotton in a composite core sheath composition was found to be better than normal polyester/cotton (PC) blended fabrics [14]. Moreover, PC fabrics with higher ratio of polyester in lower face of fabric have better moisture management capability [15]. Different chemical finishing treatments such as caustic soda and hydrophilic nanoemulsion treatments have also been developed for textiles to improve their moisture management properties [16-20]. However, a minimum level of moisture is still present, which may be acceptable if comfort is considered, but it may become the source of bacterial growth on body.

Developing a finishing treatment that not only manages the moisture produced by the body but also controls the bacterial growth can be a new advancement in the field, as it will not only help to control the bacterial growth but also improve the comfort. The aim of the present work is to functionalize PC fabric with ZnO nanoparticles to improve the moisture management and to prevent the growth of bacteria.
2. Materials and method

This study was carried out on plain woven fabric (40 × 40/80 × 68) having 70% polyester and 30% cotton with aerial density of 124 g/m². The fabric was desized, scoured, and bleached before treatment. Zinc oxide (ZnO) nanoparticles were prepared by sol–gel method using different concentrations of zinc acetate dihydrate (ACS reagent grade, Merck) and sodium hydroxide (Merck) (Table 1). Zinc acetate dihydrate Zn(CH₃COO)₂·H₂O was dissolved in methanol by stirring at 60°C for 20 min. Similarly, sodium hydroxide (NaOH) was dissolved in methanol by stirring at 60°C for 10 min. The solutions were mixed together by adding NaOH solution drop by drop in Zn(CH₃COO)₂·H₂O with continuous stirring, and the mixture was stirred for 2 h at 60°C. The chemical reactions for this synthesis are as shown in equations 1–3 [21]. The size of synthesized nanoparticles was determined by Zetasizer (Malvern). The suspension produced from the above reaction was applied on fabric by pad-dry-cure method. Fabric samples padded in solution were dried at 120°C for 2 min and cured at 150°C for 4 min. The samples were then tested for their antimicrobial and moisture management properties using the standard test methods AATCC 147 with Staphylococcus aureus and AATCC 195, respectively.

\[
\Delta G = (-K T / \Omega) \ln(C/C_0) \quad \text{(eq. 4)}
\]

where \(C\) (mol/m³) is the concentration of growth species and \(C_0\) (mol/m³) is the equilibrium concentration of growth species, \(K = 1.3806488 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}\), \(T\) is the temperature in K, \(\Omega\) is the volume per molecule (cubic meter per molecule). In order to lower the Gibbs free energy of system, the growth species aggregates to form bigger particles [22]. As the concentration of zinc acetate dihydrate is constant, therefore, the change in sodium hydroxide concentration changes the amount of growth species in suspension. The similar trend has already been observed on the growth of ZnO nanoparticles [23].

The as-prepared nanoparticles were applied to fabric by padding method. Being cellulosic in nature, the cotton carries high number of hydroxyl groups. The nanoparticles are attached to cotton fabric because of the polarity of hydroxyl groups. The polyester fibers do not have any polar groups. In order to attach nanoparticles on them, the polar groups were generated by hydrolysis of ester linkage using caustic soda [24]. Figure 1 presents the SEM images of samples treated with solutions 1 and 5. It is quite clear from these micrographs that the sample treated with solution 1 has very fine particles covering the fibers, whereas the sample treated with solution 5 has very big particles on fiber surface.

3. Results and Discussion

3.1. Functionalization of Fabric

The fabric was functionalized with ZnO nanoparticles that were prepared by sol–gel method according to chemical concentrations given in Table 1. With the increase in alkali concentration while keeping zinc acetate dihydrate concentration constant (sample 1–5 in Table 1), the appearance of particle suspension changes from complete transparent to slightly milky and then complete milky. This indicates that the particle size of ZnO increases with the increase in alkali concentration. Equations 1–3 show that with the increase in caustic soda concentration, the more and more growth species (ZnO) are produced, which cause the increase in Gibbs free energy of the system (according to equation 4).

\[
\Delta G = (-K T / \Omega) \ln(C/C_0) \quad \text{(eq. 4)}
\]

3.2. Antibacterial activity

The antibacterial activity of treated fabric was evaluated qualitatively using AATCC 147 method. Figure 2 shows the zones of inhibition around fabric samples treated with nanoparticle suspension 1–5 (Table 1). It can be seen that the fabric samples treated with smaller particle suspensions have bigger zones of inhibitions (biggest for transparent suspension) as compared to the ones treated with bigger particle size suspensions. The sample treated with suspension 1 (Figure 1a) has very small particle of just 30 nm but its zone of inhibition is

![Figure 1. SEM images of treated samples, (a) solution 1 and (b) solution 5](http://www.autexrj.com/260)
bigger as compared to the one treated with suspension 5 with particles of 410 nm (Figure 1b; Table 1).

The zone of inhibition is due to two possible reasons. The ZnO nanoparticles generate reactive oxygen species such as hydroxyl free radicals and peroxide ions. The hydroxyl radicals are highly oxidative in nature with very high redox potential and nonselective [25]. These radicals attack the bacterial membranes and oxidize them, which lead to their disintegration and finally their death.

The second important reason of zones of inhibitions is the solubility of ZnO in bacterial culture that produces Zn\(^{2+}\) ions. These ions attach on cell membranes because of electrostatic interaction as bacteria carry negative charge. Owing to this attachment, the membrane become impermeable and destroys the respiratory systems of bacteria. The solubility of particles increases with the decrease in particle size. Smaller the particle size, higher is the surface area as well as surface free energy, which causes its dissolution in solution [26]. The zone of inhibition increases with decrease in particle size. The smaller particles dissolve more producing higher amount of Zn\(^{2+}\).

### 3.3. Moisture management

Moisture management of a fabric is its ability to transport the moisture, and its measurement is based on the ability of fabric to repel, resist, or absorb the moisture [27]. A fabric’s ability to manage the moisture in contact with it depends on rates of moisture absorption, its wetting time, and area and speed of wetting. As is the case with antimicrobial properties, the moisture management capability of fabrics under study also improves with decrease in particle size. This trend has been summarized in Figure 3, which shows a decreasing trend in overall moisture management capability (OMMC) of fabric samples treated with nanoparticle suspensions having different particle sizes. OMMC is an indication of the ability of a fabric to manage the moisture in it. It is a key property that determines the comfort characteristics of a fabric, particularly, for sportswear applications [27].

Superior moisture management by finer particles can be attributed to higher moisture flow through them. Moisture flow through capillaries normally depends on the radius of capillaries. Normally, finer capillaries lead to higher flow speed. In current work, fine particles lead to finer capillaries in space between them which allow transporting the moisture quickly as compared to larger capillaries present between larger particles. The capillaries between larger particles are wide; thus they allow lower moisture flow, lower spreading speed and thus a lower absorption rate, consequently, resulting in a lower moisture management.

### 4. Conclusions

Textile for active wear must deal with the effects produced by moisture on performance and health of wearer. Accumulation of moisture next to the body not only produces a feeling of discomfort but it is also a media for the growth of many different types of microbes. In this study, both these problems have been addressed by application of ZnO nanoparticles on fabric. The resulting fabric was found not only to control the bacterial growth but also to effectively drain away the unwanted moisture through its extra-ordinary wicking properties. Such fabrics, once commercialized, can find extensive usage in sportswear, work wear, and other similar textile applications.

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**Table 1. Concentration of chemicals used for the preparation of nanoparticles**

| Solution No. | Zinc Acetate 2.Hydrate (g/100 ml Methanol) | NaOH (g/100 ml Methanol) | Size of nanoparticles (nm) |
|--------------|------------------------------------------|---------------------------|-----------------------------|
| 1            | 2                                        | 0.33                      | 50                          |
| 2            | 2                                        | 0.66                      | 130                         |
| 3            | 2                                        | 0.99                      | 260                         |
| 4            | 2                                        | 1.32                      | 380                         |
| 5            | 2                                        | 1.65                      | 650                         |
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