Comparative study of multifunctional properties of synthesised ZnO and MgO NPs for textiles applications

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Abstract

Purpose – Among various metal oxide nano particles, MgO NPs and ZnO nanoparticles (NPs) in particular are gaining increasing attention due to their multifunctional characteristics, low cost and compatibility with textile materials. Each type of nanoparticle excels over others in certain properties. As such, it is often crucial to carry out comparative studies of NPs to identify the one showing higher efficiency/output for particular applications of textile products.

Design/methodology/approach – In the investigation reported in this paper, ZnO NPs and MgO NPs were synthesised via sol-gel technique and characterised. For comparative analysis, the synthesised NPs were evaluated for multiple properties using standard procedures before and after being applied on cotton fabrics by a dip-pad-dry-cure method.

Findings – XRD and FTIR analyses confirmed the successful synthesis of ZnO and MgO NPs. Homogeneous formation of desired NPs and their dense and uniform deposition on the cotton fibre surface were observed using SEM. ZnO NPs and MgO NPs coatings on cotton were observed to significantly enhance self-cleaning/stain removal properties achieving Grade 5 and Grade 4 categories, respectively. In terms of ultraviolet (UV) protection, ZnO or MgO NP coated fabrics showed UPF values of greater than 50, i.e. excellent in blocking UV rays. MgO NPs exhibited 20% cleaning efficiency in treating reactive dye wastewater against ZnO NPs which were 4% efficient in the same treatment, so MgO was more suitable for such type of treatments at low cost. Both NPs were able to impart multifunctionality to cotton fabrics as per requirement of the end products. However, ZnO NPs were better for stain removal from the fabrics while MgO NPs were appropriate for UV blocking.

Originality/value – It was therefore clear that multifunctional textile products could be developed by employing a single type of cost effective and efficient nano particles.

Keywords Antibacterial, Effluent treatment, MgO NPs, Self-cleaning, UV blocking, ZnO NPs

Paper type Research paper

1. Introduction

One of the manufacturing sectors that has drawn tremendous gains from nanotechnology is the textile sector. The application of nanotechnology in textiles has resulted in significant diversification and modification of the intrinsic properties of conventional textiles, for instance in improving the durability, comfort, hygiene-related characteristics (Payne, 1997; Lee *et al.*, 2003; Gorenšek and Recelj, 2007; Sun *et al.*, 2009) and self-cleaning properties, etc. (Haji *et al.*, 2016; Dumitrescu *et al.*, 2020). Furthermore, application of nanotechnology has demonstrated that conventional textile products can be transformed into materials having an entirely new set of properties with an overall enhancement in the functionality too (Yuranova *et al.*, 2006). To achieve the desired functionality, a range of materials from polymeric products (Chirilă *et al.*, 2020; Tadesse *et al.*, 2020) to metals in different forms (Balci *et al.*, 2014) are reportedly used.

To optimally fulfil the needs of different industries, including textiles, a large number of natural as well as synthetic materials have been studied by researchers globally for their potential utilisation as nano-materials. Among various classes of materials that are widely researched in the field of nanotechnology, metals in their elemental or other forms such as oxides have drawn considerable interest of the research community (Haji *et al.*, 2013a; Haji *et al.*, 2013b). Metal oxide nanoparticles (NPs) exhibit a number of functional characteristics such as electrical conductivity, thermal conductivity, antibacterial/bactericidal action, ultraviolet (UV) protection, self-cleaning, odour and stain prevention, etc. (Anita *et al.*, 2011; Solanki *et al.*, 2011). Owing to their characteristic high surface area to volume ratio, metal oxides NPs are generally very efficient in delivering the desired functionality. Moreover, these materials are well-known for

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Pigment & Resin Technology
51/3 (2022) 301–308
 [ISSN 0369-9420]
[DOI 10.1108/PRT-02-2021-0017]

The authors would like to acknowledge NED Alumni Association of Southern California for funding this research.

Received 10 February 2021
Revised 31 March 2021
Accepted 5 April 2021

their ability in general to withstand stringent processing and end-use conditions (Li *et al.*, 2007; Abramov *et al.*, 2009).

Metal oxide NPs such as zinc oxide (ZnO) and magnesium oxide (MgO) are known to have a substantially low cost in comparison to nano-silver, which is arguably the most common nanoparticle that is very widely studied for its applications in the field of functional textiles as well. Furthermore, such metal oxide NPs exhibit multifunctional characteristics which could be considered useful for the textile industry. For instance, owing to their photo-catalytic nature and good adsorption properties, ZnO and MgO NPs can be employed for wastewater treatment of dye effluent from the textile industry (Tan *et al.*, 2015; Tayeb *et al.*, 2019) and for adsorption of harmful materials in gaseous form (Rajagopalan *et al.*, 2002; Li and Klabunde, 1991; Sundarrajan *et al.*, 2010). Other examples of potential applicability of ZnO and MgO NPs in textiles include anti-bacterial, self-cleaning, anti-corrosive and antifungal characteristics of these materials (Tang and Lv, 2014; Esteban-Tejeda *et al.*, 2015; Saravanan, 2007; Bharathi Yazhini and Gurumallesh Prabu, 2015; Saad *et al.*, 2016; Wang *et al.*, 2013). Furthermore, application of these NPs on textile fabrics has been shown to lead to significant improvement in the ultraviolet protection factor (UPF) of the textile material, which otherwise has a low degree of UV blocking (Becheri *et al.*, 2008). Such metal oxides can furnish the desired functionality when deposited in their as-produced form, in modified form (Tang *et al.*, 2006b, Bedilo *et al.*, 2002; Fangli *et al.*, 2003) or in combination with other materials such as polymer matrices (Vigneshwaran *et al.*, 2006; Tang *et al.*, 2006a).

A number of studies has reported comparative assessment of the properties of various metallic oxides (Kathirvelu *et al.*, 2008; Sawai, 2003; Sójka-Ledakowicz *et al.*, 2008). For instance, differences in the photo-catalytic activity of ZnO prepared by different methods has been reported in one study (Saravanan *et al.*, 2013a), whereas in another study ZnO was compared with other metal oxides including copper, nickel and tin for use as a catalyst for degradation of textile dyes (Gnanasekaran *et al.*, 2017). It has been demonstrated that a nano-composite of ZnO with silver and CdO can achieve photo-catalytic activity for textile effluent treatment in visible light (Saravanan *et al.*, 2011). A similar property has been reported for PolyAniline/ZnO composite (Saravanan *et al.*, 2016) and ZnO/CuO composite (Saravanan *et al.*, 2013b). Similarly, MgO has been studied as an adsorbent for textile dyes on its own (Darvishi Cheshmeh Soltani *et al.*, 2016; Mahmoud *et al.*, 2016; Nassar *et al.*, 2017), as well as in modified form (Asgari *et al.*, 2019), for use in medical textiles (Ponnuvelu *et al.*, 2016) and in smart textiles (Du *et al.*, 2013). These two materials have also been used in combination with each other for various textile-related applications (Raj *et al.*, 2020).

A review of the literature has revealed that both ZnO and MgO in the form of nano-particles could potentially be useful for several applications in the textile sector. These materials are often also compared for differences in their properties. However, most relevant studies evaluate one or two properties only. Thus, in this study, we investigated multiple, textile-relevant properties of ZnO and MgO nano particles that were synthesised using the sol-gel technique. This technique allows fabrication of nano particles having a uniform particle size distribution by synthesis at relatively low temperatures (Mastuli *et al.*, 2012; Epifani *et al.*, 2006). Homogeneity is required for NPs so that when applied on textile materials, uniformity of desired properties throughout the treated article can be achieved. In this study, the synthesised NPs were characterised, formulated into finishing liquor and applied onto cotton fabric through a dip-pad-dry-cure method. The antibacterial activity, stain release, UV-blocking and effluent decolourisation properties were evaluated by standard methods and comparative analyses were conducted.

2. Materials and methods

2.1 Materials

Zinc nitrate hexahydrate (>98.0%), citric acid monohydrate (99.5%), magnesium nitrate hexahydrate (>98.0%), sodium hydroxide (>97.0%) and sodium lauryl sulphate (98.5%) were purchased from Dae Jung Chemicals, Korea. Ethanol (≥99.8%, Sigma Aldrich) was used as received. Commercially scoured and bleached 100% cotton [115 g/m^2; plain weave] fabric was used.

2.2 Synthesis of ZnO nanoparticles

Equal mole (1 M) of zinc nitrate hexahydrate and citric acid monohydrate were dissolved into 100 mL of deionised water and the solution was stirrer for 60 min at 90°C which led the reaction solution to self-combustion. After combustion, the grounded powder was subjected to calcination for 3 hours at 600°C in a furnace. Scheme 1 depicts the formation of ZnO NPs.

Scheme 1: Synthesis of ZnO NPs by sol-gel method:

$$Zn(NO_3)_2 + C_6H_8O_7 + 4O_2 \rightarrow ZnO + 6CO_2 + 11H_2O$$

2.3 Synthesis of MgO nanoparticles

Magnesium nitrate hexahydrate (5.21 g, 0.1 M) was dissolved in 200 mL of distilled water at room temperature. To this, 200 mL of 0.1 M sodium hydroxide solution was added drop wise with a gentle stirring over a period of 30 min. The stirring was continued for another 3 h, and then the reaction mixture was allowed to settle for 6 h. The supernatant solution was discarded, and the remaining suspension was washed with distilled water (50 mL × 3). The white precipitates were collected and allowed to dry at 100°C in a hot air oven for 6 h. The dried precipitates were ground well and calcinated at 400°C for 4 h. Scheme 2 depicts the formation of MgO NPs.

Scheme 2: Synthesis of MgO NPs by sol-gel method:

$$Mg(NO_3)_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaNO_3$$

$$Mg(OH)_2 \rightarrow MgO + H_2O$$

2.4 Coating of fabric

Synthesised NPs (ZnO and MgO) were coated on the cotton fabric by dip-pad-dry-cure method. Before application, synthesised NPs were suspended in deionized water and were dispersed using mechanical stirrer. Thus, a sample of 100% cotton fabric was dipped in a suspension containing ZnO NPs (2%) or MgO NPs (2%) and citric acid (3%) for 1 h. The

cotton fabric sample was then passed through a padding mangle to maintain a wet pick-up of 100%. After padding, the sample was air-dried and then cured for 3 min at 140°C. The coated fabric sample was then immersed in sodium lauryl sulphate (2 g/L) solution for 5 min, to remove any unbound NPs. The fabric sample was then rinsed 10 times to washout the soap completely and then air dried. The coated samples were conditioned under standard conditions.

2.5 Characterisation of ZnO and MgO nanoparticles

X-ray diffraction pattern of the synthesised NPs was obtained using the PANalytical X'pert pro X-ray diffractometer using Cu-Kα radiation of wavelength λ =0.1541 nm. In addition, the average crystallite size of the synthesised NPs was calculated using Scherrer's formula:

$$L = \frac{k\lambda}{\beta \cos\vartheta}$$

where L is an average crystallite size, λ is the wavelength of X-ray radiation (0.1541 nm), K is a constant equal to 0.9, β is Full-width half maximum of the peak (in radians) and 2θ is Bragg's angle (degree).

Infrared spectra of synthesies NPs were recorded using Spectrum One spectrophotometer (Perkin Elmer, UK). Each spectrum was acquired using 0.09 cm^{-1} resolution and 16 scans per spectrum and the vibrational frequencies are reported in wavenumbers (cm^{-1}).

Morphological features of the synthesised NPs, uncoated and coated cotton fabric samples were studied using a JEOL JSM-6380A scanning electron microscope. For surface morphology, the synthesised NPs and the coated cotton fabric samples were coated with up to 300 °A gold.

2.6 Antibacterial activity

The antibacterial activity of the synthesised NPs and coated fabric samples were tested according to AATCC TM-147 (the agar diffusion method). A sterile nutrient agar solution was prepared and placed in plates and then left to solidify. Once solidified, a cork broker was used to make holes and then the bacterial culture was spread on the agar with the help of a cotton bud. The coated fabric samples were gently pressed in the centre of the mat culture and the plates are left to be incubated for 24 h at 37°C. The zone of inhibition was examined to obtain the antibacterial activity .

2.7 Stain release properties

The uncoated and coated cotton fabric samples were stained with drops of ketchup and left under 2 kg weight for 1 min. The residual stain was rated in comparison with an AATCC TM-130 stain-release replica immediately, after 3 h, 5 h and after washing.

2.8 Ultraviolet-blocking properties

The UV blocking of the uncoated and coated fabric samples were measured using AATCC TM-183. Thus, two samples of 2 × 2 inches were taken and placed on the transmission port of the Specord 200 Plus (Analytik Jena, Germany) UV-VIS spectrophotometer and the readings were recorded.

2.9 Decolourisation efficiency

Decolorisation efficiency of the synthesized NPs was measured by comparing the absorbence of a test dye solution before and after the addition of NPs. For this purpose, a Specord 200 Plus (Analytik Jena, Germany) spectrophotometer was used. The test dye solution containing 10 Wt.% of the selected reactive dye was prepared and the pH was set at 9.0 by using 0.1 N solution of NaOH. 0.05 g of the synthesized NPs was added and the solution was stirred at 450 RPM for 10 min followed by stirring at 40 RPM for another 10 min. The mixture was then left to rest for 30 min and the supernatant samples were collected for the measurement of absorbence.

3. Results and discussion

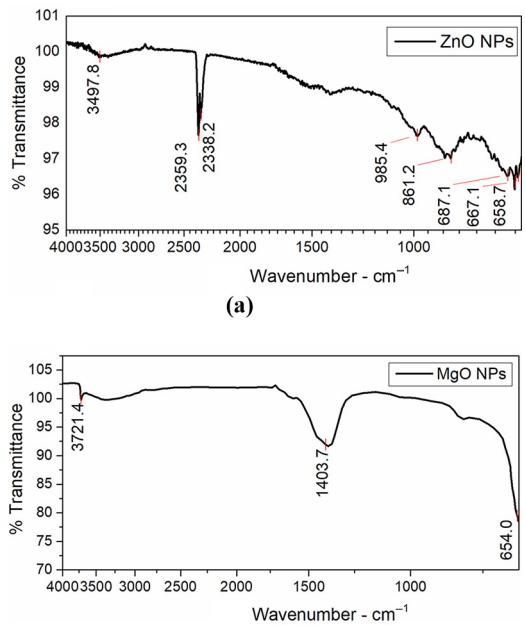
3.1 Characterisation of synthesised ZnO and MgO nanoparticles

X-ray diffraction patterns to characterise the synthesised ZnO and MgO NPs were obtained as described in Section 2.5. As shown in Figure 1(a), the XRD peaks are in good agreement with JCPDF card No. 01–076-0704 (Jamshidi Bandari and Nasirian, 2019). Moreover, no impurities were detected suggesting that high-quality ZnO NPs were synthesised. The average crystallite size of the synthesised ZnO NPs was found to be 20 nm.

Similarly, the XRD peaks shown in Figure 1(b) are in good agreement with JCPDF card No. 01–089-7746 (Imani and Safaei, 2019a, Mantilaka *et al.*, 2014) and no characteristic peaks for any impurities were detected. Thus, the analysis clearly suggests that high-quality MgO NPs were synthesised, for which the average crystallite size was found to be 9 nm.

To further validate the aforementioned analysis, the FTIR spectra of the synthesized NPs were also obtained. Figure 2(a) shows the FTIR spectra of the synthesised ZnO NPs.

Figure 1 XRD Spectra of the synthesised

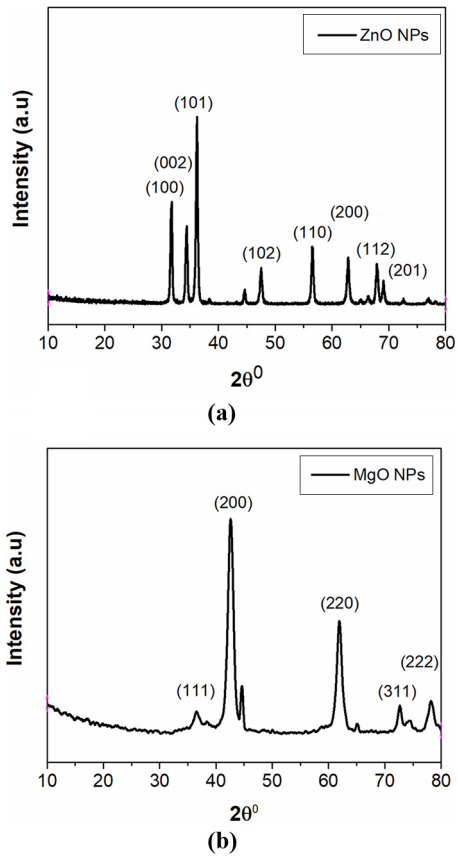


(a)

(b)

Notes: (a) ZnO NPs (b) MgO NPs

Figure 2 FTIR Spectra of the synthesised



Notes: (a) ZnO NPs; (b) MgO NPs

The vibration bands at 2359.3 cm^{-1} and 2338.2 cm^{-1} can be attributed to atmospheric CO_2. (Arshad *et al.*, 2011) The sharp peaks observed in the range of 687.1 to 558.7 cm^{-1} can be attributed to the Zn−O bond (Getie *et al.*, 2017; Shaban *et al.*, 2018; Saoud *et al.*, 2015; Costa *et al.*, 2018).

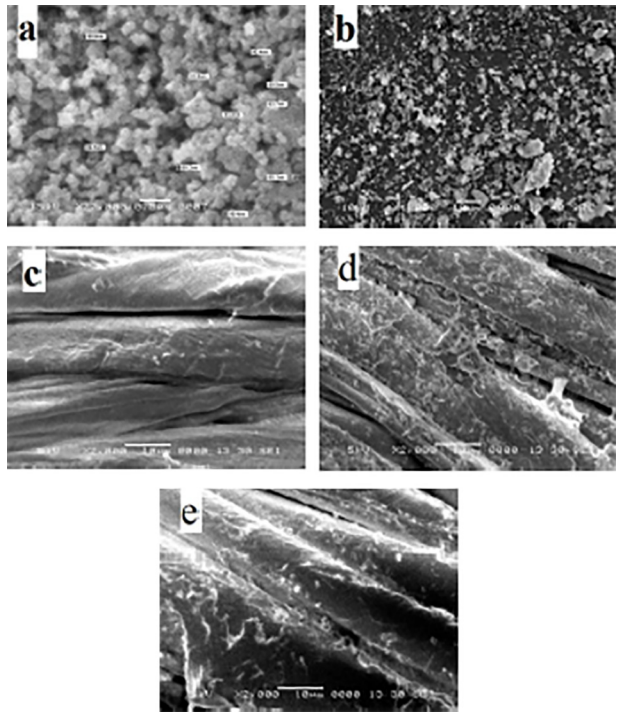
Similarly, for the synthesised MgO particles, the FTIR spectra is shown in Figure 2(b). The peak at 3721.4 cm^{-1} belong to the O-H group whereas the peaks at 1403.7 cm^{-1} and 654.0 cm^{-1} correspond to Mg-O stretching vibration (Alfaro *et al.*, 2019; Shi *et al.*, 2017; Imani and Safaei, 2019b, Gajengi *et al.*, 2017).

The morphology of the synthesised ZnO and MgO NPs, uncoated and coated cotton fabric samples was observed by SEM and relevant micrographs are shown in Figures 3(a-e). Figure 3(a) shows the SEM image of the synthesised ZnO NPs in powder form. It clearly shows the spherical nature of the prepared NPs. Furthermore, it can also be observed that the ZnO NPs obtained are homogeneous in nature and agglomerated with an average particle size between 80 – 85 nm.

Figure 3(b) shows the SEM image of the synthesised MgO NPs in powder form. The image shows a highly agglomerated structure of MgO NPs which are almost spherical in shape with an average particle size between 30 and 40 nm. The differences between particles in SEM and XRD data may be due to agglomeration of particles.

Figure 3(c)-(e) shows the morphological changes induced on cotton surface coated with the synthesised NPs. In contrast to the

Figure 3 SEM micrographs of (a) ZnO NPs Powder; (b) MgO NPs Powder; (c) uncoated Cotton Fabric; (d) ZnO NPs coated Cotton Fabric; and (e) MgO NPs coated Cotton Fabric

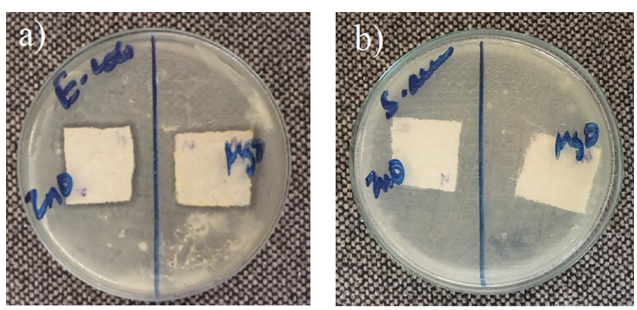


SEM micrograph of uncoated cotton fabric [Figure 3(c)], the micrograph of the cotton fabric coated with ZnO [Figure 3(d)] and MgO NPs [Figure 3(e)] shows a dense and uniform deposition of NPs on the cotton fibre surface.

3.2 Antibacterial activity

The antibacterial property of the fabric coated with the synthesised ZnO and MgO NPs was evaluated against E. Coli and S. Aureus using the Agar Diffusion method. For this, 15 mm × 15 mm swatches of the coated fabric were laid onto the inoculated agar plates. The images of the agar plates recorded after a 24 h incubation period at 37°C are provided in Figure 4. It was observed that both ZnO and MgO NPs, in the

Figure 4 Agar method results of the synthesised ZnO and MgO NPs against



Notes:(a) Gram-negative bacterial strains; (b) Gram-positive bacterial strains

form of coating on fabric, exhibited bacteriostatic property against E. Coli, as evident from a distinct zone of inhibition that can be seen in Figure 4(a). On the other hand, neither the ZnO coated fabric nor the MgO coated fabric showed any activity against S. Aureus. Similar results have been reported in other studies as well and can be attributed to structural differences in the cell of gram-positive and gram-negative bacteria (Brayner *et al.*, 2006). Furthermore, the absence of inhibition zone in the case of gram-positive bacteria, as shown in Figure 4(b), could be related to low migration rate of the NPs from the coating onto the nutrient agar (D'água *et al.*, 2018)

3.3 Stain release properties

To evaluate the stain release properties of the coating, the coated and uncoated samples were stained with drops of ketchup. The residual stain was graded on a scale by comparing it with stain-release replica that is used in AATCC test method 130. According to the stain release replica of AATCC Test Method 130, Grade 1 indicates substantial residual stain (poor stain removal) whereas Grade 5 indicates minimal residual stain (complete removal). A useful fabric in this context would be one that achieves a grade of at least 4. Relevant results of this test that are shown in Table 1 indicate that both ZnO and MgO NPs exhibited acceptable self-cleaning/stain release properties with the ZnO coated fabric showing significantly enhanced self-cleaning/stain removal properties.

3.4 Ultraviolet-blocking properties

As discussed in the preceding literature review, most metal oxide NPs including ZnO and MgO possess excellent UV absorption ability. Thus, the coated cotton fabrics were expected to exhibit UV-blocking property which is often expressed quantitatively as UP). UPF is defined as the ratio of the average effective UV irradiance of an unprotected (uncovered) surface, e.g. skin, to the effective UV irradiance on that surface in the presence of a protective layer which in this case is the fabric. A UPF of greater than 50 is generally regarding as an indicator of excellent UV-blocking property of a sheet material such as a woven fabric. The relevant results of this analysis are provided in Table 2 and Figure 5. As shown in Figure 5, the black spectrum obtained for the uncoated cotton fabric shows high transmission of UV through it and the corresponding UPF was found to be 20. In contrast, the UPF values for the ZnO coated fabric and the MgO coated fabric were found to be 58 and 71, respectively. Thus, it can be concluded that coating of cotton fabric with the synthesised ZnO and MgO NPs imparts UV-blocking functionality in the fabric.

3.5 Decolourisation efficiency

Flocculation experiment for the removal of residual dye was performed. The dye removal efficiency of the synthesised NPs is presented in Figure 6. Almost 4% and 20% of efficiency was achieved at 0.05 g/L of dosage for the synthesised ZnO NPs and MgO NPs, respectively. The result indicated that the synthesised MgO NPs was effective for treating reactive dye wastewater as compared to the synthesised ZnO NPs.

Table 1 Stain grading of uncoated and NPs coated cotton fabrics

Time	Uncoated	ZnO NPs coated cotton	MgO NPs coated Cotton
At 0 hours	Grade 1	Grade 2	Grade 2
At 3 hours	Grade 2	Grade 3	Grade 3
At 5 hours	Grade 2	Grade 4	Grade 3
After washing	Grade 3	Grade 5	Grade 4

Table 2 UV (Ultraviolet)-blocking properties of the uncoated, ZnO-coated and MgO-coated fabrics

Sample	UPF	UV Protection Category (ASTM D 6603)	UVA (315–400 nm)	UVB (280–315 nm)
Uncoated fabric	21 (20)	Good	5.51	4.14
ZnO NPs coated Fabric	58 (50+)	Excellent	1.65	1.21
MgO NPs coated Fabric	71 (50+)	Excellent	2.04	1.45

Figure 5 UV transmittance spectra of uncoated and coated cotton fabrics

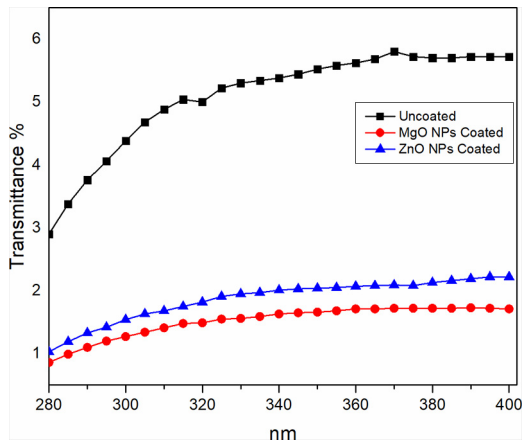
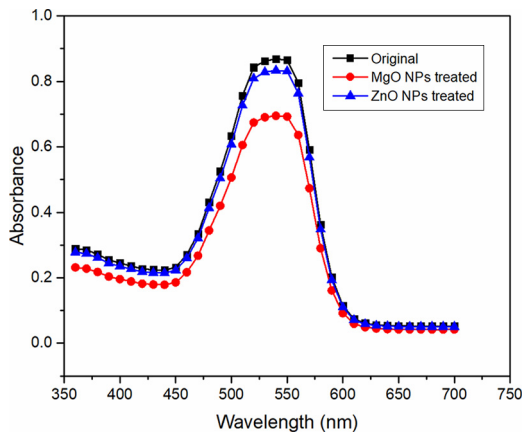


Figure 6 UV-VIS spectrum of original and treated effluents



4. Conclusion

In this investigation, homogenous, uniform and cost effective ZnO NPs and MgO NPs were synthesised by sol-gel technique. Characterisation and evaluation of relevant properties were conducted on uncoated and coated cotton fabrics for

comparative analyses so suitable NPs could be identified for the textile products required to have multifunctional properties as per their end use. It was found that the two types of synthesised NPs did not excel at the same level in all of the properties evaluated in this study. Indeed, although each of the two types of NPs had multiple characteristics, it was not possible to use any one type of NPs to achieve multiple properties on the fabrics at the optimum. Nevertheless, the type of NPs that achieve higher/the highest grade as per standard for the specific properties can be selected for delivering process and products of greater efficiency and cost effectiveness.

References

Abramov, O.V., Gedanken, A., Koltypin, Y., Perkas, N., Perelshtein, I., Joyce, E. and Mason, T.J. (2009), "Pilot scale sonochemical coating of nanoparticles onto textiles to produce biocidal fabrics", *Surface and Coatings Technology*, Vol. 204 No. 5, pp. 718-722, doi: 10.1016/j.surfcoat.2009.09.030.

Alfaro, A., León, A., Guajardo, E., Reuquen, P., Torres, F., Mery, M., Segura, R., Zapata, P.A. and Orihuela, P.A. (2019), "MgO nanoparticles coated with polyethylene glycol as carrier for 2-methoxyestradiol anticancer drug", *PLoS One*, Vol. 14 No. 8, pp. 1-12, doi: 10.1371/journal.pone.0214900.

Anita, S., Ramachandran, T., Rajendran, R., Koushik, C. and Mahalakshmi, M. (2011), "A study of the antimicrobial property of encapsulated copper oxide nanoparticles on cotton fabric", *Textile Research Journal*, Vol. 81 No. 10, pp. 1081-1088, doi: 10.1177/0040517510397577.

Arshad, M., Azam, A., Ahmed, A.S., Mollah, S. and Naqvi, A.H. (2011), "Effect of Co substitution on the structural and optical properties of ZnO nanoparticles synthesized by sol–gel route", *Journal of Alloys and Compounds*, Vol. 509 No. 33, pp. 8378-8381, doi: 10.1016/j.jallcom.2011.05.047.

Asgari, G., Faradmal, J., Nasab, H.Z. and Ehsani, H. (2019), "Catalytic ozonation of industrial textile wastewater using modified C-doped MgO eggshell membrane powder", *Advanced Powder Technology*, Vol. 30 No. 7, pp. 1297-1311, doi: 10.1016/j.apt.2019.04.003.

Balci, O., Tanriverdi, A., Alver, Ü., Tutak, M. and Beşen, B.S. (2014), "In-situ generation of ZnO on the textile surfaces by hydrothermal method", *Industria Textila*, Vol. 65 No. 2, pp. 80-84.

Becheri, A., Dürr, M., Lo Nostro, P. and Baglioni, P. (2008), "Synthesis and characterization of zinc oxide nanoparticles: application to textiles as UV-absorbers", *Journal of Nanoparticle Research*, Vol. 10 No. 4, pp. 679-689, doi: 10.1007/s11051-007-9318-3.

Bedilo, A.F., Sigel, M.J., Koper, O.B., Melgunov, M.S. and Klabunde, K.J. (2002), "Synthesis of carbon-coated MgO nanoparticles", *Journal of Materials Chemistry*, Vol. 12 No. 12, pp. 3599-3604, doi: 10.1039/B207972K.

Bharathi Yazhini, K. and Gurumallesh Prabu, H. (2015), "Study on flame-retardant and UV-protection properties of cotton fabric functionalized with ppy–ZnO–CNT nanocomposite", *RSC Adv.*, Vol. 5 No. 61, pp. 49062-49069, doi: 10.1039/C5RA07487H.

Brayner, R., Ferrari-Iliou, R., Brivois, N., Djediat, S., Benedetti, M.F. and Fiévet, F. (2006), "Toxicological impact studies based on Escherichia coli bacteria in ultrafine ZnO nanoparticles colloidal medium", *Nano Letters*, Vol. 6 No. 4, pp. 866-870, doi: 10.1021/nl052326h.

Chirilă, L., Constantinescu, G.C., Danila, A., Popescu, A., Constantinescu, R.R. and Săndulache, I.-M. (2020), "Functionalization of textile materials with bioactive polymeric systems based on propolis and cinnamon essential oil", *Industria Textila*, Vol. 71 No. 2, pp. 186-192, doi: 10.35530/IT.071.02.1793.

Costa, S.M., Ferreira, D.P., Ferreira, A., Vaz, F. and Fangueiro, R. (2018), "Multifunctional flax fibres based on the combined effect of silver and zinc oxide", *Nanomaterials*, Vol. 8 No. 12, pp. 1-21, doi: 10.3390/nano8121069.

d'Água, R.B., Branquinho, R., Duarte, M.P., Maurício, E., Fernando, A.L., Martins, R. and Fortunato, E. (2018), "Efficient coverage of ZnO nanoparticles on cotton fibres for antibacterial finishing using a rapid and low cost in situ synthesis", *New Journal of Chemistry*, Vol. 42 No. 2, pp. 1052-1060, doi: 10.1039/C7NJ03418K.

Darvishi Cheshmeh Soltani, R., Safari, M. and Mashayekhi, M. (2016), "Sonocatalyzed decolorization of synthetic textile wastewater using sonochemically synthesized MgO nanostructures", *Ultrasonics Sonochemistry*, Vol. 30, pp. 123-131, doi: 10.1016/j.ultsonch.2015.11.018.

Du, P., Song, L., Xiong, J., Wang, L. and Li, N. (2013), "A photovoltaic smart textile and a photocatalytic functional textile based on co-electrospun TiO2/MgO core–sheath nanorods: novel textiles of integrating energy and environmental science with textile research", *Textile Research Journal*, Vol. 83 No. 16, pp. 1690-1702, doi: 10.1177/0040517513490062.

Dumitrescu, I., Iordache, O.-G., Mitran, C.-E., Perdum, E., Săndulache, I.-M., Secăreanu, L.O., Dincă, L.C., Sobetkii, A. and Diamandescu, L. (2020), "Attempts to improve the self-cleaning effect of the textile materials", *Industria Textila*, Vol. 71 No. 3, pp. 252-258, doi: 10.35530/IT.071.03.1626.

Epifani, M., Díaz, R., Arbiol, J., Comini, E., Sergent, N., Pagnier, T., Siciliano, P., Faglia, G. and Morante, J.R. (2006), "Nanocrystalline metal oxides from the injection of metal oxide sols in coordinating solutions: synthesis, characterization, thermal stabilization, device processing, and Gas-Sensing properties", *Advanced Functional Materials*, Vol. 16 No. 11, pp. 1488-1498, doi: 10.1002/adfm.200500652.

Esteban-Tejeda, L., Prado, C., Cabal, B., Sanz, J., Torrecillas, R. and Moya, J.S. (2015), "Antibacterial and antifungal activity of ZnO containing glasses", *PLoS One*, Vol. 10 No. 7, pp. 1-17, doi: 10.1371/journal.pone.0132709.

Fangli, Y., Peng, H., Chunlei, Y., Shulan, H. and Jinlin, L. (2003), "Preparation and properties of zinc oxide nanoparticles coated with zinc aluminate", *Journal of Materials Chemistry*, Vol. 13 No. 3, pp. 634-637, doi: 10.1039/B208346A.

Gajengi, A.L., Sasaki, T. and Bhanage, B.M. (2017), "Mechanistic aspects of formation of MgO nanoparticles under microwave irradiation and its catalytic application", *Advanced Powder Technology*, Vol. 28 No. 4, pp. 1185-1192, doi: 10.1016/j.apt.2017.02.004.

Getie, S., Belay, A., Chandra Reddy, A. and Belay, Z. (2017), "Synthesis and characterizations of zinc oxide nanoparticles for antibacterial applications", *Journal of Nanomedicine & Nanotechnology*, Vol. s8, pp. 1-8, doi: 10.4172/2157-7439.S8-004.

Gnanasekaran, L., Hemamalini, R., Saravanan, R., Ravichandran, K., Gracia, F., Agarwal, S. and Gupta, V.K. (2017), "Synthesis and characterization of metal oxides (CeO2, CuO, NiO, Mn3O4, SnO2 and ZnO) nanoparticles as photo catalysts for degradation of textile dyes", *Journal of Photochemistry and Photobiology B: Biology*, Vol. 173, pp. 43-49, doi: 10.1016/j.jphotobiol.2017.05.027.

Gorenšek, M. and Recelj, P. (2007), "Nanosilver functionalized cotton fabric", *Textile Research Journal*, Vol. 77 No. 3, pp. 138-141, doi: 10.1177/0040517507076329.

Haji, A., Barani, H. and Qavamnia, S. (2013a), *In Situ Synthesis and Loading of Silver Nanoparticles on Cotton Fabric. Industria Textilă*, Vol. 64 No. 1, pp. 8-12.

Haji, A., Barani, H. and Qavamnia, S.S. (2013b), "In situ synthesis of silver nanoparticles onto cotton fibres modified with plasma treatment and acrylic acid grafting", *Micro & Nano Letters*, Vol. 8 No. 6, pp. 315-318, doi: 10.1049/mnl.2013.0157.

Haji, A., Mousavi Shoushtari, A., Mazaheri, F. and Tabatabaeyan, S.E. (2016), "RSM optimized self-cleaning nano-finishing on polyester/wool fabric pretreated with oxygen plasma", *The Journal of the Textile Institute*, Vol. 107 No. 8, pp. 985-994, doi: 10.1080/00405000.2015.1077023.

Imani, M.M. and Safaei, M. (2019a), "Optimized synthesis of magnesium oxide nanoparticles as bactericidal agents", *Journal of Nanotechnology*, Vol. 2019, pp. 1-6, doi: 10.1155/2019/6063832.

Imani, M.M. and Safaei, M. (2019b), "Optimized synthesis of magnesium oxide nanoparticles as bactericidal agents", *Journal of Nanotechnology*, Vol. 2019, p. 6063832, doi: 10.1155/2019/6063832.

Jamshidi Bandari, A. and Nasirian, S. (2019), "Carbon monoxide gas sensing features of zinc oxide nanoneedles: practical selectivity and long-term stability", *Journal of Materials Science: Materials in Electronics*, Vol. 30 No. 11, pp. 10073-10081, doi: 10.1007/s10854-019-01111-8.

Kathirvelu, S., D'souza, L. and Dhurai, B. (2008), "A comparative study of multifunctional finishing of cotton and P/C blended fabrics treated with titanium dioxide/zinc oxide nanoparticles", *Indian Journal of Science and Technology*, Vol. 1 No. 6, pp. 1-12.

Lee, H.J., Yeo, S.Y. and Jeong, S.H. (2003), "Antibacterial effect of nanosized silver colloidal solution on textile fabrics", *Journal of Materials Science*, Vol. 38 No. 10, pp. 2199-2204, doi: 10.1023/A:1023736416361.

Li, Y.X. and Klabunde, K.J. (1991), "Nano-scale metal oxide particles as chemical reagents. Destructive adsorption of a chemical agent simulant, dimethyl methylphosphonate, on heat-treated magnesium oxide", *Langmuir*, Vol. 7 No. 7, pp. 1388-1393, doi: 10.1021/la00055a017.

Li, Q., Chen, S.-L. and Jiang, W.-C. (2007), "Durability of nano ZnO antibacterial cotton fabric to sweat", *Journal of Applied Polymer Science*, Vol. 103 No. 1, pp. 412-416, doi: 10.1002/app.24866.

Mahmoud, H.R., Ibrahim, S.M. and El-Molla, S.A. (2016), "Textile dye removal from aqueous solutions using cheap MgO nanomaterials: adsorption kinetics, isotherm studies and thermodynamics", *Advanced Powder Technology*, Vol. 27 No. 1, pp. 223-231, doi: 10.1016/j.apt.2015.12.006.

Mantilaka, M.M.M.G.P.G., Pitawala, H.M.T.G.A., Karunaratne, D.G.G.P. and Rajapakse, R.M.G. (2014), "Nanocrystalline magnesium oxide from dolomite via poly (acrylate) stabilized magnesium hydroxide colloids", *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol. 443, pp. 201-208, doi: 10.1016/j.colsurfa.2013.11.020.

Mastuli, M.S., Ansari, N.S., Nawawi, M.A. and Mahat, A.M. (2012), "Effects of cationic surfactant in sol-gel synthesis of nano sized magnesium oxide", *APCBEE Procedia*, Vol. 3, pp. 93-98, doi: 10.1016/j.apcbee.2012.06.052.

Nassar, M.Y., Mohamed, T.Y., Ahmed, I.S. and Samir, I. (2017), "MgO nanostructure via a sol-gel combustion synthesis method using different fuels: an efficient nano-adsorbent for the removal of some anionic textile dyes", *Journal of Molecular Liquids*, Vol. 225, pp. 730-740, doi: 10.1016/j.molliq.2016.10.135.

Payne, J. (1997), "From medical textiles to smell-free socks", *Journal of the Society of Dyers and Colourists*, Vol. 113, pp. 48-50, doi: 10.1111/j.1478-4408.1997.tb01866.x.

Ponnuvelu, D.V., Selvaraj, A., Suriyaraj, S.P., Selvakumar, R. and Pulithadathail, B. (2016), "Ultrathin hexagonal MgO nanoflakes coated medical textiles and their enhanced antibacterial activity", *Materials Research Express*, Vol. 3 No. 10, pp. 1-12, doi: 10.1088/2053-1591/3/10/105005.

Raj, B., Umadevi, M. and Parimaladevi, R. (2020), "Enhanced photocatalytic degradation of textile dyeing wastewater under UV and visible light using ZnO/MgO nanocomposites as a novel photocatalyst", *Particulate Science and Technology*, Vol. 38 No. 7, pp. 812-820, doi: 10.1080/02726351.2019.1616863.

Rajagopalan, S., Koper, O., Decker, S. and Klabunde, K.J. (2002), "Nanocrystalline metal oxides as destructive adsorbents for organophosphorus compounds at ambient temperatures", *Chemistry – A European Journal*, Vol. 8 No. 11, pp. 2602-2607, doi: 10.1002/1521-3765(20020603)8:11<2602::AID-CHEM2602>3.0.CO;2-3.

Saad, S.R., Mahmed, N., Abdullah, M.M.A.B. and Sandu, A.V. (2016), "Self-cleaning technology in fabric: a review", *IOP Conference Series: materials Science and Engineering*, Vol. 133 No. 1, pp. 1-9, doi: 10.1088/1757-899X/133/1/012028.

Saoud, K., Alsoubaihi, R., Bensalah, N., Bora, T., Bertino, M. and Dutta, J. (2015), "Synthesis of supported silver nano-spheres on zinc oxide nanorods for visible light photocatalytic applications", *Materials Research Bulletin*, Vol. 63, pp. 134-140, doi: 10.1016/j.materresbull.2014.12.001.

Saravanan, D. (2007), "UV protection textile materials", *AUTEX Research Journal*, Vol. 7 No. 1, pp. 53-62.

Saravanan, R., Gupta, V.K., Narayanan, V. and Stephen, A. (2013a), "Comparative study on photocatalytic activity of ZnO prepared by different methods", *Journal of Molecular Liquids*, Vol. 181, pp. 133-141, doi: 10.1016/j.molliq.2013.02.023.

Saravanan, R., Shankar, H., Thanigainathan, P., Narayanan, V. and Arumainathan, S. (2011), "ZnO/CdO composite nanorods for photocatalytic degradation of methylene

blue under visible light", *Materials Chemistry and Physics*, Vol. 125 Nos 1/2, pp. 277-280, doi: 10.1016/j.matchemphys.2010.09.030.

Saravanan, R., Karthikeyan, S., Gupta, V.K., Sekaran, G., Narayanan, V. and Stephen, A. (2013b), "Enhanced photocatalytic activity of ZnO/CuO nanocomposite for the degradation of textile dye on visible light illumination", *Materials Science and Engineering: C*, Vol. 33 No. 1, pp. 91-98, doi: 10.1016/j.msec.2012.08.011.

Saravanan, R., Sacari, E., Gracia, F., Khan, M.M., Mosquera, E. and Gupta, V.K. (2016), "Conducting PANI stimulated ZnO system for visible light photocatalytic degradation of coloured dyes", *Journal of Molecular Liquids*, Vol. 221, pp. 1029-1033, doi: 10.1016/j.molliq.2016.06.074.

Sawai, J. (2003), "Quantitative evaluation of antibacterial activities of metallic oxide powders (ZnO, MgO and CaO) by conductimetric assay", *Journal of Microbiological Methods*, Vol. 54 No. 2, pp. 177-182, doi: 10.1016/S0167-7012(03)00037-X.

Shaban, M., Mohamed, F. and Abdallah, S. (2018), "Production and characterization of superhydrophobic and antibacterial coated fabrics utilizing ZnO nanocatalyst", *Scientific Reports*, Vol. 8 No. 1, pp. 1-15, doi: 10.1038/s41598-018-22324-7.

Shi, J., Kantoff, P.W., Wooster, R. and Farokhzad, O.C. (2017), "Cancer nanomedicine: progress, challenges and opportunities", *Nature Reviews Cancer*, Vol. 17 No. 1, pp. 20-37, doi: 10.1038/nrc.2016.108.

Sójka-Ledakowicz, J., Lewartowska, J., Kudzin, M., Jesionowski, T., Siwińska-Stefańska, K. and Krysztafkiewicz, A. (2008), "Modification of textile materials with micro- and nano-structural metal oxides", *Fibres and Textiles in Eastern Europe*, Vol. 16, pp. 112-116.

Solanki, P.R., Kaushik, A., Agrawal, V.V. and Malhotra, B.D. (2011), "Nanostructured metal oxide-based biosensors", *NPG Asia Materials*, Vol. 3 No. 1, pp. 17-24, doi: 10.1038/asiamat.2010.137.

Sun, L., Rippon, J.A., Cookson, P.G., Koulaeva, O. and Wang, X. (2009), "Effects of undoped and manganese-doped zinc oxide nanoparticles on the colour fading of dyed polyester fabrics", *Chemical Engineering Journal*, Vol. 147 Nos 2/3, pp. 391-398, doi: 10.1016/j.cej.2008.11.032.

Sundarrajan, S., Chandrasekaran, A.R. and Ramakrishna, S. (2010), "An update on nanomaterials-based textiles for protection and decontamination", *Journal of the American Ceramic Society*, Vol. 93 No. 12, pp. 3955-3975, doi: 10.1111/j.1551-2916.2010.04117.x.

Tadesse, M., Loghin, E.-C., Nierstrasz, V. and Loghin, M.-C. (2020), "Quality inspection and prediction of the comfort of fabrics finished with functional polymers", *Industria Textila*, Vol. 71 No. 4, pp. 340-349, doi: 10.35530/IT.071.04.1734.

Tan, K.B., Vakili, M., Horri, B.A., Poh, P.E., Abdullah, A.Z. and Salamatinia, B. (2015), "Adsorption of dyes by nanomaterials: recent developments and adsorption mechanisms", *Separation and Purification Technology*, Vol. 150, pp. 229-242, doi: 10.1016/j.seppur.2015.07.009.

Tang, Z.-X. and Lv, B.-F. (2014), "MgO nanoparticles as antibacterial agent: preparation and activity", *Brazilian Journal of Chemical Engineering*, Vol. 31 No. 3, pp. 591-501, doi: 10.1590/0104-6632.20140313s00002813.

Tang, E., Cheng, G. and Ma, X. (2006a), "Preparation of nano-ZnO/PMMA composite particles via grafting of the copolymer onto the surface of zinc oxide nanoparticles", *Powder Technology*, Vol. 161 No. 3, pp. 209-214, doi: 10.1016/j.powtec.2005.10.007.

Tang, E., Cheng, G., Ma, X., Pang, X. and Zhao, Q. (2006b), "Surface modification of zinc oxide nanoparticle by PMAA and its dispersion in aqueous system", *Applied Surface Science*, Vol. 252 No. 14, pp. 5227-5232, doi: 10.1016/j.apsusc.2005.08.004.

Tayeb, A.M., Tony, M.A. and Ismaeel, E.K. (2019), "Engineered nanostructured ZnO for water remediation: operational parameters effect, box–behnken design optimization and kinetic determinations", *Applied Water Science*, Vol. 9 No. 3, pp. 1-11, doi: 10.1007/s13201-019-0921-0.

Vigneshwaran, N., Kumar, S., Kathe, A.A., Varadarajan, P.V. and Prasad, V. (2006), "Functional finishing of cotton fabrics using zinc oxide–soluble starch nanocomposites", *Nanotechnology*, Vol. 17 No. 20, pp. 5087-5095, doi: 10.1088/0957-4484/17/20/008.

Wang, W.L., Yi, T.J., Zhou, Y.J. and Chen, G.H. (2013), "Research on anti-UV and anti-bacterial properties of multi-functional finishing on silk fabric with nano-MgO", *Advanced Materials Research*, Vol. 796, pp. 98-102, doi: 10.4028/www.scientific.net/AMR.796.98.

Yuranova, T., Mosteo, R., Bandara, J., Laub, D. and Kiwi, J. (2006), "Self-cleaning cotton textiles surfaces modified by photoactive SiO2/TiO2 coating", *Journal of Molecular Catalysis A: Chemical*, Vol. 244 Nos 1/2, pp. 160-167, doi: 10.1016/j.molcata.2005.08.059.

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