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Nano silver in antimicrobial textiles

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***Abstract* - Textiles are flexible materials consisting of a web of fibres. These fibres can be exposed to microbial contamination, which leads to decline in the quality of the textile. Nanotechnology can be integrated into the process of manufacturing textiles to make them less susceptible to microbial degradation, particularly in the case of special usage textiles. This article discusses how nanosilver can be employed as an antimicrobial agent in textiles. Silver nanoparticles, in low concentrations are not harmful to the human body and have a broad spectrum of antimicrobial actions. Not only do the textiles have the ability to exhibit antibacterial functions but they also exhibit high efficiency and excellent durability.**

This paper further illustrates the synthesis and optimizing of silver nanoparticles from fungus filtrate, green (leaf and fruit extracts) and other sources and their characterization; the embedding of the nanoparticles into wool, silk, cotton fabrics and leather; the examining of the finished fabrics for their features and characterization ; and the testing of these fabrics using sophisticated techniques. Additionally, there is a brief discussion on the laundering scenarios of the treated fabrics. There is also a brief discussion on the self-cleaning ability of textiles.

Keywords- Nanotechnology; Nanosilver; Antimicrobial; Synthesis; Characterization

I. INTRODUCTION

Textile fibres, due to their intrinsic properties, are susceptible to microbial damage. Nanotechnology evokes the attention of the textile industry as it can be used to incorporate antimicrobial properties in textile materials. Textiles are given an antimicrobial finish for the following reasons: (1) to hold off diseases from spreading externally, (2) to prevent stench due to sweat and organic stains, (3) to curb textile degradation caused by mildew.

Natural fibres like cotton are hygroscopic and are highly moisture retentive and hence serves as a nutrient base for microbes. Due to this there is discolouration, loss in mechanical strength, generation of foul odour, reduction in air permeability, adverse harmful impact on human beings.

Silver and silver ions have suppressive and bactericidal effect. Owing to their high surface energy and surface to volume ratio even in small concentrations, silver nanoparticles exhibit higher antimicrobial activity as compared to bulk silver. When coatings of nanoparticles are applied onto fabrics, they form bonds with the fibres of the material and the surface to volume ratio is proportional to the strength of the bond.

In this review paper, we have briefed some of the green methods of synthesis from leaf extract of *Melia azedarach L.*; *Pedalium murex* leaf extract; *Ocimum sanctum*; flower extract of *Erigeron annuuspers*; aqueous solution of extracted dye from pomegranate peel; fruit extract of *Vitisvinifera*; fungi *Fusariumsolani*;. *Aspergillus terreus B.* Other methods of synthesis in the article in situ synthesis of nanoparticles on silk, cotton and wool; electrolytic aerosol process.

It gives an understanding of the embedding process of AgNPs on the fabric and its antimicrobial activity. The AgNPs synthesised were then characterised and the modifications that the fabrics were subjected to are tested for the activity, launderability and durability.

II. EXPERIMENTAL METHODS

Nanosilver can be synthesized both green and chemical processes discussed as below

A. Green synthesis

A.a. Synthesis from leaf extract of Melia azedarach

This experiment was a simple one step method for the synthesis of AgNPs using the leaf extracts of *Meliaazedarach* (Family, Meliaceae). The extract served as a reducing agent of Ag^{+} ions to AgNPs (Ag^{0}). The process took place at room temperature without the use of additives for preventing the aggregation of AgNPs.

5 grams of fresh leaves was washed with both tap and distilled water, air dried, cut into fine pieces, boiled in a microwave for 10 minutes. The extract obtained was cooled at room temperature and filtered. 4 mM of silver nitrate solution was prepared.

100 ml of leaf extract and 100 ml of silver nitrate solution (aq.) was kept at room temperature in an Erlenmeyer flask. The colour change was because of excitation in Surface

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Plasmon Resonance which indicated the formation of AgNPs. The fabric was tested after modification against *Proteus spp,Klebseilla pneumonia, Escherichia coli, Staphylococcus aureus,*and *Pseudomonas aeruginosa* by agar disc diffusion method.
The experiment showed higher antibacterial effect against *S. aureus* as compared to other tested bacteria. It is a quick process to get large amounts of AgNP[1].

A.b. Synthesis from using Pedalium murex leaf extract

Pedalium murex (*P. murex*), of the sesame family, Pedaliaceae, is a popular locally acclaimed herbal drug. The research was performed to study the synthesis of AgNPs from *Pedalium murex* extract and determine their characterization.

Fresh extract acts as a reducing agent to reduce Ag^{+} ions to Ag^{0}. Solutions were prepared by drying the leaves and grounding them into a fine powder in an Erlenmeyer flask. 5g of powder was boiled with 100ml distilled water for 10 min and the mixture was decanted, further filtrate obtained on filtration through Whitman no.1 filter paper was stored at 4 °C.

Varying concentrations of leaf extracts from 1 to 5 ml were prepared separately and added to 10 ml of 0.01 mM $AgNO_3$ prepared solution. After a period of 20 min, the colour of the mixture gradually transitioned from light yellow to dark brown, indicating the formation of AgNPs. The AgNP colloidal solution was analyzed using UV–Vis spectrophotometer.

The antibacterial activity of three different concentrations of AgNPs was carried out against seven different microorganisms*: Staphylococcus aureus, Bacillus subtilis, Micrococcus flavus,Klebsiellapheumoniae, Bacillus pumilus, Pseudomonas aeruginosa* and *Escherichia coli.*

In the study, the biosynthesised AgNPs had the highest antibacterial activity against *B. subtilis* and *E. coli* respectively. Lesser antibacterial activity of AgNPs is observed against *M. flavus, B. pumilus, P. aeruginosa, K. pneumoniae,* and *S. aureus*, while increasing the concentrations of AgNP from 5, 10, 15 µl/ml. The observed bacterial group incubations around the wall were due to the diffusible inhibitory compounds released from the AgNPs[10].

A.c.. Synthesis from Ocimum sanctum

A highly efficient and promising method of rapid green synthesis of AgNPs is a one step process wherein, the aqueous extract of *Ocimum sanctum* renowned for its medicinal properties, acts as both a reducing agent as well as a capping agent. It reduces the Ag^{+} ions, in aqueous silver nitrate solution by irradiation by direct sunlight, with no chemical additives and we arrive at a product of excellent stability and antibacterial properties.

The results obtained were compared with *Citrus limon* Linn. and *Justiciaadhatoda* Linn. under the same conditions.

Fresh and healthy leaves of *O. sanctum, C. limon,* and *J. adhatoda* were collected thoroughly cleansed and cut into fine pieces, which were each transferred to three different 250ml beakers with distilled water and boiled for 10 min. The extract is cooled and filtered. The filtrates were stored in three 100ml flasks for storage. On the dilution of the respective mother extract (10%) with amount of distilled water, aqueous extracts of concentrations varying from 7%, 5%, and 3% were used in the process.

The solutions were exposed to direct sunlight; a gradual colour change, which indicates silver nanoparticle formation, was confirmed by UV-vis spectrophotometric studies at regular time intervals. The solutions of all three plant extracts were analysed and compared.

The primary compounds are eugenol, β-caryophyllene, β-elemene, cyclopropylidene, carvacrol, linalool, germacrene, etc. are responsible for photo-induced bio-reduction of silver metal ions followed by stabilization of the nanoparticles formed.

Eugenol, being dominant amongst the chemical constituents, a probable mechanism for the rapid photo-induced bio-reduction process could be as follows: On sunlight irradiation, within the phenolic group in Eugenol, O-H bond forms a hydrogen radical by homolytic cleavage, which transfers its electron to the Ag^{+}, AgNP. The oxygen radical stabilizes in the solution by extended conjugation. Thus the increasing concentration H^{+} ions affects the pH of the resulting AgNPs-PLE medium.

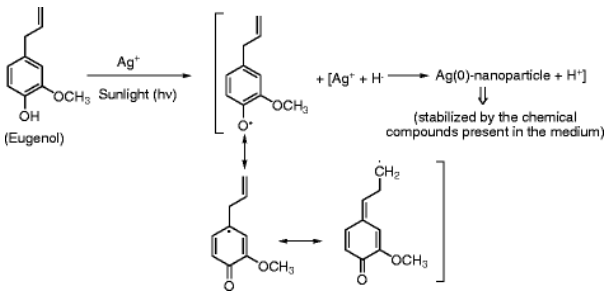

Figure 1: Reaction for synthesis of AgNPs from Eugenol [11]

The qualitative antimicrobial screening was done by the agar well diffusion experiment, wherein the samples were tested against eight bacteria and clear inhibition zones of varying sizes were observed.

The samples were quantitatively verified by CFU count method after treating each bacterial culture with the plant extracts as well as the AgNP formed by them after proper dilution and plating on their suitable growth media and incubating overnight. It was inferred that AgNP formed by the 7% aqueous leaf extract imparted the best antimicrobial

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action indicating the definite role of *O. sanctum* extract as well in enhancing the antibacterial potential and also resulted in AgNPs of smaller size than those obtained by the other concentration of extracts tested[11].

A.d. Synthesis from Flower extract of Erigeron annuuspers

In this experiment, AgNPs were fabricated using *Erigeron annuus (L.) pers* flower (family Asteraceae) extract as reducing and capping agent for fabric and leather finishing. 100g of the flowers were crushed in a juicer along with 250 ml of distilled water and the extract was filtered through a Whattman filter paper. It was stored at 4◦C. Silver nitrate (99.9%) and silver nano powder were obtained.

In a 250 ml Erlenmeyer flask, 5 ml of the flower extract was added to 45ml of 1mM aqueous $AgNO_3$ solution. A Steritop Millipore filter was used to filter the reaction mixture followed by centrifugation for 15 minutes at 12,000 rpm. The pellets obtained were redispersed in nanopure water to rid them of any uncoordinated molecules. The process was repeated a number of times and the resulting NPs were stored freeze-dried to obtain a powder. The stability of the AgNPs were checked by exposing to ambient condition for several months and scanned for the wavelength.

Before embedding of the prepared NPs on the surface of the textile, certain preliminary adjustments need to be made. The leather was punched in order to get spherical shape and sliced to reduce the thickness by removing the smooth surface. The leather was immersed in boiling water (50 ml) with 2ml/l of non-ionic detergent for an hour, followed by washing with hot and cold water to avoid break down of the emulsion and precipitation of the impurities onto the leather. It is then air-dried at room temperature. In the case of cotton, 3 g of the fabric treated in the same way. The samples were immersed in 50ml screw cap tubes with the respective form of prepared AgNPs and kept in an ultrasonicator for 20min at 70 ◦C at 100Hz after which the samples were pressed with tissue paper. This is followed by drying at 120◦C for 2 min in the case of cotton fabrics at 80◦C for 15 min in the case of leather.

The zone of inhibition and minimum bacterial concentrations for the treated fabrics were determined against *B. linens* and *S. epidermidis*. The results indicated that for the above experiment, cotton fabric exhibited greater reduction of B. linens growth, followed by leather sample. There is uniformity in ZOI of S. epidermidis in cotton fabric and leather samples[2].

A.e. Extracted dye from pomegranate peel

In this experiment, AgNPs were synthesized by a biochemical reduction method. AgNPs were synthesised from silver nitrate using an aqueous solution of a dye extracted from pomegranate peel and deposited on wool fabrics. There is a considerable amount of tannin in the rind of *Punicagranatum L.* (pomegranate). Granatonine is the main colouring agent present in the peel.

For extraction of the dye, 10 g of pomegranate powder and 400 ml of a methanol/water solution were taken in a round bottom flask. It is placed on a heating plate and refluxed for 15 minutes. The extract was filtered using a Whattman filter and the filtrate was heated in an oven at 40◦C for 24 hours and the powder obtained was refrigerated. An aqueous solution of extracted dye fromwas prepared by dilution (0.2 g extracted dye in 100 mL of deionized water). The aqueous solutions of 100 ppm $AgNO_3$ and the extract were mixed in required amounts keeping the dye to silver ratio 0.1, 1 and 10. These were mixed with distilled water to a final volume of 50 ml.

The antibacterial activity of synthesized AgNPs were determined against *Escherichia coli.* Testing was done using a bacteriostatic agar-based test (ATCC 11229) result was expressed in terms of the size of the ZOI (in mm)[3].

A.f. Synthesis from Vitisvinifera fruit extract

Pedalium murex (P. murex), of the sesame family, Pedaliaceae, is a popular locally acclaimed herbal drug. The research was performed to study the synthesis of AgNPs from *Pedalium murex* extract and determine their characterization.

Fresh extract acts as a reducing agent to reduce Ag^+ ions to Ag^0. Solutions were prepared by drying the leaves and grounding them into a fine powder in an Erlenmeyer flask. 5g of powder was boiled with 100ml distilled water for 10 min and the mixture was decanted, further filtrate obtained on filtration through Whitman no.1 filter paper was stored at 4 °C.

Varying concentrations of leaf extracts from 1 to 5 ml were prepared separately and added to 10 ml of 0.01 mM $AgNO_3$ prepared solution. After a period of 20 min, the colour of the mixture gradually transitioned from light yellow to dark brown, indicating the formation of AgNPs. The AgNP colloidal solution was analyzed using UV–Vis spectrophotometer.

The antibacterial activity of three different concentrations of AgNPs was carried out against seven different microorganisms*: Staphylococcus aureus, Bacillus subtilis, Micrococcus flavus,Klebsiellapheumoniae, Bacillus pumilus, Pseudomonas aeruginosa* and *Escherichia coli.*

In the study, the biosynthesised AgNPs had the highest antibacterial activity against *B. subtilis* and *E. coli*

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respectively. Lesser antibacterial activity of AgNPs is observed against *M. flavus, B. pumilus, P. aeruginosa, K. pneumoniae, and S. aureus,* while increasing the concentrations of AgNP from 5, 10, 15 µl/ml. The observed bacterial group incubations around the wall were due to the diffusible inhibitory compounds released from the AgNPs[9].

A.g. Synthesis from fungi Fusariumsolani

This study is based a fungi-based technique using the *Fusariumsolani* strain for the preparation of silver nanoparticles solution which is environmentally safe. The fermentation medium consisted of sodium nitrate (2 g/l), magnesium sulfatepentahydrate (0.5 g/l), potassium chloride (0.5 g/l), potassium dihydrogen phosphate (1 g/l), trace amount of ferrous sulfate, sucrose (20 g/l), and pH was adjusted at 6.5–7. It was contained in a 250 ml conical flask and inoculated with *Fungus F. solani*. The pH was adjusted at 6.5 - 7. It was incubated at 30 - 32◦C. After 72 h, the biomass is harvested by filtration followed by followed by washing with distilled water. This was taken in a 250 ml conical flask containing 100 ml of distilled water which was kept for 72 h at 30 - 32◦C followed by separation of the aqueous solution components by filtration. To this, $AgNO_3$ was added and it was maintained under ambient condition (25◦C) for 48 h.

Testing was done on treated fabric, untreated fabrics and treated fabrics after being subjected to repeated washing against *S. aureus* and *E. coli*. The reduction of bacterial colonies was higher than 90% against both *S. aureus* and *E. coli* for AgNP treated samples without washing. When the treated cotton fabrics were subjected to five washing cycles, there was a decrement in the reduction of bacterial colonies to just above 70%. The same when subjected to 10 or 20 washing cycles leads to marginal reduction in antibacterial properties. By incorporating the binder in the finishing bath formulation, the antibacterial properties of the cotton fabric are enhanced even after 20 washing cycles[5].

A.h. Synthesis from Aspergillus terreus B

Dried cotton fabrics were washed with double distilled water, sterilized by autoclaving at 121 °C for 15 min at 15 lbs. pressure. *A. terreus* was grown in potato dextrose broth (PDB) and was incubated at 27 °C for 7 days. After incubation, 10g of the fungal mat was washed with 100ml of sterile double distilled water and kept under shaker condition of 120 rpm for 48 h at 27 °C. Filtration was carried out and the filtrate was reacted with certain quantity of silver nitrate to yield an overall Ag^+ ions. This reaction was carried out in dark at room temperature. The change in colour from colourless to brown was observed. This indicated formation of AgNPs due to excitation of surface plasmon vibrations. The sterilized fabrics were dried, immersed in flask containing the synthesized AgNPs and were continuously agitated in a rotary shaker for 24h with a speed of 120rpm at 37°C.The treated fabrics were squeezed at constant pressure for 1 min and then were dried at 70°C for 3 min in a hot air oven. Finally, the fabrics were left to stand for 2min at 120°C and then stored at room temperature in a container.

Testing was done by the following 3 methods:

Agar diffusion method: The treated fabric was tested against *Bacillus subtilis, S. aureus, Methicillin-resistant S. aureus, E. coli, Klebsiella pneumoniae* and *Pseudomonas aeruginosa* by Agar diffusion method. The test pathogens were inoculated in sterile broth and incubated at 37°C for 24 h. The grown bacterial suspension was added onto the treated and untreated fabrics. The plates containing the fabrics were incubated for 24 h at 37°C and then inhibition zone (ZOI) was recorded.

A parallel streak test: AgNPs treated fabrics of 50× 25 mm (length ×width) size were used. The test bacteria were grown in sterile nutrient broth for 18h at 37 °C. The treated fabric was slightly pressed over the bacteria grown. The fabric was incubated at 37°C. A clear zone was observed which indicated no growth along the sides of AgNPs treated fabrics, ZOI was determined. The average width of inhibition zone on the AgNPs treated fabrics was calculated using the equation, $W = \frac{T - D}{2}$

Where, W is the width of zone of inhibition (mm); T = total diameter of specimen and the zone of clearance (mm); D = diameter of the specimen (mm).

Antifungal activity: Treated and untreated cotton fabrics were used. A fungal inoculum was prepared using sterile distilled water and was evenly spread onto the plate. Then AgNPs treated and untreated patches were made wet using 0.05% nonionic wetting agent (Triton X-100) and were placed on the plates carefully. 0.2 ± 0.01 mL of fungal inoculum was distributed equally on the fabrics using sterile pipette and the plates for an incubation period of 7 days at 27°C. The antifungal activity of AgNPs treated fabrics was assessed at the end of the incubation period by determining the percentage of fungal growth over the surface of the fabric.

Launderability test: The durability of mycosynthesizedAgNPs treated cotton fabrics was evaluated after 5, 10, and 15 wash cycles. The washing process was carried out with neutral soap (5% Hiclean, HiMedia). After 30 min, the fabrics were cleansed with sterile double distilled water and then dried. This procedure was followed up to 15 wash cycles.

Treated and untreated fabric were taken in a flask. Then required quantity of the grown bacteria was added to it using a pipette. The flask was then agitated for 24hr at 37°C in a rotary shaker operating at 120rpm. After incubation, sample

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from the treated and untreated swatches were distilled. 0.1ml of the diluted solution was taken in agar plates and these plates were incubated for 24h at 37°C. The percentage of bacteria reduction was calculated with the following equation

R =Percentage reduction (%); B= Total amount of bacteria obtained from untreated swatches; A =Total amount of bacteria recovered from the treated swatches[8].

$$R = \left(\frac{B - A}{B} \right) \times 100$$

B. Chemical methods

B.a. In situ synthesis of nanoparticles on silk

The degumming of silk was done with sodium carbonate at boiling temperatures for half an hour, and then cleansed with water. The above steps were carried out twice to efficiently remove sericin (a gelatinous protein that cements the two fibroin filaments in a silk fiber.).

The silk fibers were then immersed in a 1% polyethyleneimine solution for 10min to impart the surface with positive charges.

After washing with pure water, the fibers were then treated with a 1% polyacrylic acid solution for adsorption of the first layer of negatively charged PAA.

The polydimethyldiallylammonium chloride molecules that have a positive charge, were deactivated by immersing the silk in a 1% PDDA solution.

The PAA and PDDA assembling steps were alternatively repeated to get the desired layer by layer film.

The layered silk film was soaked in a silver nitrate aqueous solution for 1 h in the presence of a 365 nm UV irradiation (3 W) for in situ growth of AgNPs. After continuous cycles of washing and drying, the modified silk was collected for the further experiments.The parameters for the production of AgNPs were controlled.

Activity: *E. coli and S. aureus* were immunized with constant agitation at a speed of 180rpm at 37°C overnight. Circular silk fabrics were placed uniformly over the inoculated bacteria in agar plates. After incubation at 37 °C for 12 h, the images of the agar plates were captured and based on the area of the inhibition zone, the antimicrobial activity was evaluated[8].

B.b. Electrolytic aerosol process.

An electrical discharge between two electrodes in inert gas flow at atmospheric pressure can also be used to synthesize silver Nanoparticles.

The process employs silver electrodes. The aerosol generator is a cylindrical chamber comprising of several ports and fabricated from stainless steel. Electrodes are inserted through the ports and positioned inside the chamber. The chamber has an inlet and outlet for the carrier gas and aerosol respectively. The alignment is such that the electrodes are placed facing each other with a distance between them. The discharge is run by a capacitor charger that is formed from a high voltage power supply.

One electrode was connected to the positive terminal of the power supply and the other electrode was grounded.

The capacitor is charged by the current supplied to a point where the voltage exceeds the breakdown voltage, after which the capacitor discharges.

This occurs as a pulse of duration of a few microseconds which repeats at a frequency that increases with current (spark discharge).

The voltage drops with the increase in the current. Then, a continuous discharge regime is attained (glow discharge).

During an electrical discharge, positive ions are projected from the plasma towards the electrode, where they collaborate with the surface atoms releasing electrons, which causes the electrode to get heated or melt at the point of contact.

Material evaporates from the electrode surface and enters the gap where small nanoparticles form from the vapor. These nanoparticles grow downwards of the plasma region[13].

C. Characterisation

UV Spectroscopy: The reduction of Ag^{+} ions to AgNPs is indicated by a visually observable transition in colour of the reaction mixture from colourless to yellow to dark brown[9]. Metallic nanoparticles possess free electrons, which can yield a plasmon resonance absorption band, owing to the vibrations of the electrons in sync with the light wave. The peaks observed characterises the SPR of the AgNP. For the bio-synthesis of AgNPs, the importance of AgNO3 and the presence of active ingredients in the extracts are shown from the UV–Vis spectrum.

The absorption by colloidal AgNP seen in the region between 400–450 nm can be attributed to the excitation of surface plasmon vibration. Sometimes we see a shift in the resonance band to a lower wavelength as the concentration increases, this may be caused by the blue shift and is dependent on the shape and particle size.

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TEM: The TEM analysis elucidates details of the shape and size of the resultant nanoparticles. The shape, size, distribution and morphology of the synthesized AgNPs were confirmed with the help of HR-TEM.

Fluorescence: The Photoluminescence spectrum of the AgNPs obtained by the various extracts are studied with the help of fluorescence emission spectroscopy. It can be used to estimate the optical property of silver nanoparticles as photonic materials. The AgNP colloidal solution is dispersed in water and the the emission spectra obtained is recorded for the excitation wavelength.

SEM: The surface morphology and size of the AgNPs obtained are determined by this method.

FTIR: The phytochemical compounds which are responsible for the reduction and further, the stabilization of synthesized AgNPs are identified and confirmed by the FTIR studies, which is also responsible for further functionalization with other molecules for diverse applications.

XRD studies:These studies confirm the presence of AgNPs and give us the structural information. The AgNPs obtained by green synthesis typically are found to be FCC. The average crystalline size of the silver nanoparticles was determined. By determining the width we can find the average size of the crystalline particles. The peaks obtained in the analysis can help us determine the phytochemical compounds as well as the silver[1].

Table 1:Characterization data for above synthesis

Method Extract					UV Spectroscopy (UV)	Scanning Electron Microscopy (SEM)	Energy Dispersive X-ray spectroscopy (EDX)	Fourier transform infrared (FTIR)	X-ray powder diffraction (XRD)	Transmission Electron Microscopy (TEM)
Leaves extract of *Melia azedarach L.* [1]					Scanning between 300-700 nm; absorption peak at 482 nm	Spherical particles in the range of 34 nm - 48 nm;	Absorption peak at 3 keV region		Crystalline nature is confirmed	
Flower extract of *Erigeron annuuspers [2]*					Scanning between 0 to 335 min; Sharp peak of absorbance at 1.5 mM Ag+ ion concentration; Time of formation of AgNPs between 15min - 3h		Strongest peak observed t ~3 keV		Crystalline nature is confirmed	Particle size range from 10nm - 20 nm
Extracted dye from pomegranate peel [3]					Solution of 50 ppm Ag+ ions analysed; peak appeared at	Almost spherical particles	Size of particles obtained is 1.256% and 0.767%		Crystalline nature is confirmed.	Particles have bimodal size distribution

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					403 nm (after 3h);					
Fungi *Fusariumsolani*[5]					Surface plasmon resonance occur at 420 nm	Higher the concentration of the AgNP colloids solution, greater the deposition.				Size range of particles between 3-8 nm
Aspergillus terreus B [8]						The SEM image revealed that the untreated surfaces had a smooth surface whereas the AgNP coated fabrics had a rough surface	the spectrum of treated cotton fabric showed maximum peaks at 3keV that is the silver region			
Pedalium murex leaf extract [10]					wavelength range for analysis of colloidal sample: 4000–400 cm−1; Absorption spectrum of the functional group: 200-800 nm; surface plasmon peak: 424 nm.	the histogram of the particle size: 20 to 50 nm.Confirms that *Pedalium murex* leaf extract act as a reducing and capping agent in the production of silver nanoparticles.	Metallic silver nanoparticles show strong absorption in the range 2.5–4 keV; The presence of elements such as Ag, O, C, K, Cl, Ca and Na.	The presence of flavonoids, alkaloids, steroids, rosins, saponins and Proteins are confirmed	The peaks indicate presence of phytochemical compounds extracts;Stronger planes imply that a major constituent in the biosynthesis is AgNP.	Spherical particles; 50 nm size;

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Ⅲ. MECHANISM OF ANTIBACTERIAL ACTIVITY OF AgNPS

There is no clear cut mechanism for the bactericidal effect of AgNPs in textiles. However, a few theories have been put forth.

Compared to bulk silver metal, nanoparticles of silver have a larger surface to mass ratio owing to their greater antimicrobial activity. The interactions of AgNPs with the fabric were studied by electron microscopy which confirmed that these were size dependent. Their nano size enables them to enter into and attach themselves to cell membranes and cause damage, bringing about structural changes affecting the vital cell functions like permeability, pit and gap formation, action of respiratory enzymes. They may also interfere with DNA replication with the microbes. All these factors are fatal and ultimately cause cell death.

The biological efficacy increases proportionately as the specific surface area of nanoparticles increases[4].

Ⅳ. MODIFIED PROPERTIES

The incorporation of AgNPs into the fabric takes a toll on both, the mechanical and physical properties of the fabric. These effects, however, haven't been thoroughly investigated. It was observed that the AgNPs did not cause significant mechanical damage or reduced comfort.

A. Physical properties

A.a.Air permeability

The volume of air (cm^3) which passes through 1 cm^2 of the fabric at a given pressure in 1s.

With the increasing concentration of AgNPs, air permeability of the fabrics reduced as a consequence of particles filling up the pores present in the fabric along with an increase in its thickness. Lower air permeability is analogous to reduced fabric comfort[12].

A.b. Thickness

Thickness was measured for bending studies. Thickness of the fabric increases with AgNP deposition[12].

A.c. Water vapor permeability

The mass of water vapour that passes through a given area (1m2) of a textile material in an hour because of the pressure difference is known as WVP. There is no considerable change in WVP with increase in concentration of AgNPs on the fabric[12].

A.d. Crease recovery

The ability of the fabric to return after wrinkling is called crease recovery. There is a decrease in crease recovery in both weft and warp directions with the increase in AgNP concentration. This change is more significant in the weft direction owing to lower weft density and more pore volume. The reason for the decrease in crease recovery of treated samples is the pore-void filling action. Lower crease recovery is not desirable because of reduced fabric comfort[12].

B. Mechanical Properties

B.a. Bending rigidity

Bending length of a fabric is the length which makes it bend at a particular angle due to its weight. It is a measure of stiffness. The bending length in both warp and weft directions is required to determine the bending rigidity.

$$G = W \times C \times 10^3$$

Where G is the bending rigidity, W is the fabric unit area weight, C is bending length

The bending rigidity is higher in treated fabrics than in untreated ones. The reason for the increase in bending rigidity of treated samples is the pore-void filling action. Due to higher warp density, the warp bending rigidity was higher. Lower flexibility results in reduced comfort[12].

B.b. Failure load

Failure load in both the warp and weft directions reduce with the application of AgNPs. This is because there may be incomplete reduction of silver salt[12].

B.c. Failure elongation

$$E\% = \frac{L - L_0}{L_0} \times 100$$

Where L_0 is the initial length of fabric, L is the length of the strip at the rupture point and $E\%$ failure elongation.

There is increased movement in the weft direction owing to higher warp density. This results in fabric elongation in the weft direction. The structure weakened due to the decrease in elongation[12].

B.d. Tear strength

The force that is needed to continue a tear in a fabric under specified conditions is defined as the tongue tear strength of fabric. Only for concentrations exceeding 300 ppm, there was a considerable drop in tear strength[12].

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V. SELF CLEANING TEXTILES

Self cleaning textiles, as the name suggests, are textile surfaces that can spontaneously cleanse themselves of bacteria, dirt and grime by means of their own physical properties. The research on this subject has immense potential and has drawn interest for fundamental research and offers enormous practical applications: daily life, military, agriculture, etc. and its progress could offer a highly positive environmental impact. Several strategies and projects have gone underway to develop, design and fabricate efficient self cleaning surfaces over the last few decades. There have been a considerable variety of self cleaning surfaces on the market lately.

There have been different synthesis techniques adopted, owing to nanotechnology and multipurpose chemical finishes, a few of which we would like to discuss. The primary inspiration for self cleaning material, is nature itself, which has by evolution demonstrated boundless illustrations of self cleaning. The technique of self cleaning discussed in this paper is biomimicry, or bio-inspired self cleaning textiles.

Self cleaning textiles can be designed by introducing the active substances into the bulk fibre or by finishing the textile with the substance. They may be coated hydrophobically or hydrophilically. The lotus plant demonstrates an excellent self cleaning mechanism by superhydrophobicity. It serves as an inspiration for the design of such textiles by what is widely known as *the lotus effect*. The dirt particles slide off easily along with water droplets on their surface.
The Gecko setae is another natural inspiration of self cleaning, wherein contaminants are cleaned primarily by contacting a dry surface with no other liquid droplets. Underwater organisms and underwater machinery are plagued by biofouling. The antifouling self cleaning effect wherein the biofouling organisms do not settle and grow on the skins of the organisms like sharks, carps, whales, etc. have inspired antifouling surfaces with special physical and chemical structures. There is also the self-cleaning based on TiO_2 arising from photocatalysis and photo-induced superhydrophilicity.

Superhydrophilicity-Induced Self-Cleaning: It is an essential surface property that accords the self cleaning property to materials. On a superhydrophilic surface, water spreads out and forms a thin film. Rain or light sprays, on flowing on such surfaces can wedge into spaces between the substrate and any dirt present, thereby washing it away.

Superhydrophobicity: The roots of the lotus are ingrained in dirt or impure water, but we have observed that the leaves of the plant are ostensibly clean. This is because of its superhydrophobic nature which causes droplets falling onto the leaves to bead up and roll away. Rainwater has been washing off the dirt off these plants, hence they self clean. This is the lotus effect. It has a a very low roll-off angle of about 2° and a very high static water contact angle, greater than 160°[14] [15] [16].

AgNPs have a very large specific surface area as well as a high reactivity towards proteins and thus increased contact with pathogens, increasing its antibacterial or fungicidal effectiveness. Their antibacterial properties, their non toxicity and their ability to absorb visible light makes AgNPs excellent candidates to manufacture nano enhanced self cleaning textiles.

At RMIT, researchers from the Ian Potter NanoBioSensing Facility and NanoBiotechnology Research Lab worked with silver and copper based nanostructures (known for their ability to absorb visible light) and integrated them with textiles so that they may degrade organic matter when simply exposed to light. The two metals are cost effective and due to LSPR, demonstrate intense properties of absorbance in the visible region making them an ideal choice for promoting photocatalytic reactions. The challenges faced by researchers has been to bring the concept on an industrial scale with nanostructures permanently attached to the textiles [17].

VI. DISCUSSIONS

AgNPs due to their high surface energy and specific surface area, have demonstrated excellent antibacterial properties and their applications to textiles have shown to reduce their biodegradability and pathogenic activity. The textiles integrated with AgNPs are gaining immense potential in this age. The green synthesis method of synthesising the silver nanoparticles is much more favourable, as opposed to the general method of chemical reduction as a colloidal dispersion in water or organic solvents. These methods are eco-friendly, utilize non-toxic, even medicinal natural compounds. Silver nanoparticles were synthesized by environmentally safe methods which minimize the addition of hazardous wastes in the environment apart from aerosol method where high temperatures can lead to formation of aggregates thatcannot be broken into its initial parts.
During the synthesis, the solution turned brown in colour because of the excitation in surface Plasmon resonance wherein, it indicated the formation of silver nanoparticles. The synthesized nanoparticles were spherical, 34–48 nm in size, crystalline in nature and showed an absorption

spectrum at 482 nm characterized by using different techniques.

Silver nanoparticles have been proved safer because of their non-resistant nature in comparison to conventional antibiotics. It has been observed that nearly 50% of the antibacterial activity was reduced after 20cycles of washing. A binder (0.1% by weight) was suggested to increase the durability. AgNPs treated fabrics showed excellent laundering and durability even after 15 wash cycles. This application can be used to produce antiseptic dressing or bandage for medical purposes in the near future.

In-situ synthesis controls the distribution of AgNPs on the fabric but the increase rate of oxidation of AgNPs with time was a major drawback. This involved the use of a metal ion precursor, a reducing agent and a stabilizing agent, to prevent aggregation of created particles. In situ synthesis of nanoparticles is a simple and effective route to prepare nanocomposites. This method allows one-step procedure for obtaining nanocomposites[7].

In the ex situ approach, silver nanoparticles were prepared using chemical or physical methods. There are many chemical methods reported to synthesize silver nanoparticles like the aerosol method discussed in this paper. For large scale synthesis ex-situ is more suitable than in-situ [7].

Application of AgNPs does not damage the fabric but alters the properties. The bending rigidity of the treated fabric was increased due to the pore filling action. It was also found that high concentrations of AgNPs about 500ppm resulted in reduction in failure elongation, air permeability, tear strength, and tensile strength of treated fabrics. Reduced silver nitrate concentration promoted a slight acidic environment in the finishing solution and diminished the mechanical performance. It was concluded that AgNPs concentrations above 300 ppm could adversely influence the comfort and mechanical performance of the treated fabrics

Self cleaning textiles are a revolutionary technology that could do away with washing machines in a distant future, but the textiles are still at their formative stages and it could take some time before they are completely commercialized and used by the masses. The proven efficacy of Copper and Silver nanoparticles make them ideal for further research and scaling up. The goals of research in this field would be production of ultra hydrophobic fabrics on a large scale.

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