USE OF NANO SILVER AS AN ANTIMICROBIAL AGENT FOR COTTON

A.I. Wasif and S.K. Laga

Textile & Engineering Institute,
Ichalkaranji 416115, India
E-mail: swapan_laga@yahoo.co.in

Abstract:

In the present study, an attempt has been made to impart antimicrobial finishing on cotton woven fabric using nano silver solution, at various concentrations: 5 gpl, 10 gpl, 15 gpl, 20 gpl, and 25 gpl in the presence of PVOH (5 gpl, 7.5 gpl and 10 gpl) and an eco-friendly cross linking agent, namely 100gpl glyoxal/65 gpl Appretan N 92111 (binder) applied by the pad-dry-cure technique. Curing conditions were varied, keeping curing temperatures at 140 oC, 150 oC, and 160 oC and curing times to 1 min., 2 mins., and 3 mins. To assess the quality of the finished fabric, various properties like tensile strength, bending length, crease recovery angle, and zone of inhibition were studied. The zones of inhibition have been studied using Staphylococcus aureus and Escherichia coli bacteria to determine antimicrobial activity. To observe the polymer formation in the finished fabric, the surface characteristics of these fabrics have been studied using Scanning Electron Microscopy (SEM). In the case of commercial Product A (Sanitized® T 27-22 Silver) treated cotton fabric, the zones of inhibition are a minimum of 24 mm and maximum of 29 mm for Gram-positive bacteria and a minimum of 14 mm and a maximum of 18 mm for Gram-negative bacteria. In the case of commercial Product-B (Sanitized® T 25-25 Silver) treated cotton fabric, the zones of inhibition are a minimum of 24 mm and a maximum of 29.5 mm for Gram-positive bacteria and a minimum 14 mm and a maximum of 18.6 mm for Gram-negative bacteria. SEM study of antimicrobial finished fabric reveals that a continuous polymer film has been formed on the fabric. The concentration of PVOH controls the bending length and crease recovery angle. The higher the concentration of PVOH, the higher will be the bending length and crease recovery angle. Curing temperature and time have a profound impact on tensile strength. The higher the curing temperature and time, the lower the tensile strength.

Key words:

Antimicrobial, nano silver, SEM, zone of inhibition

Introduction

Due to the growing demand for comfortable, clean, and hygienic textile goods, an urgent need for production of antimicrobial textile goods has arisen. With the advent of new technologies, the growing needs of consumers in terms of health and hygiene can be fulfilled without compromising issues related to safety, human health, and the environment.

Nano-scale particles provide a narrow size distribution, which is required to obtain a uniform material response. Materials such as paints, pigments, electronic inks, and ferrofluids as well as advanced functional and structural ceramics require that the particles be uniform in size and stable against agglomeration. Fine particles, particularly nano-scale particles with significant surface areas, often agglomerate to minimise the total surface or interfacial energy of the system. Although the process of using solution chemistry can be a practical route for the synthesis of both sub-micrometre and nano-scale particles of many materials, issues such as control of size, distribution of particles, morphology, crystallinity, particle agglomeration during and after synthesis, and separation of these particles from the reactant need further investigation.

The history of silver as an anti-microbial agent

The use of elemental silver as an anti-bacterial agent is nearly as old as the history of mankind. The ancient Egyptians mention the medicinal use of silver in their writings. Romans stored wine in silver urns to prevent spoilage. The courts of the Chinese emperors ate with silver chopsticks for better health. Druids used silver to preserve food. American settlers put silver dollars in milk to stop spoilage. Silver leaf was used during World War I to combat infection in wounds. Human skin has many surface bacteria present at any time; that is not a bad thing.

Microorganisms can be found almost everywhere in the environment. NASA researchers have found microorganisms even at a height of 32 km and to a depth of 11 km in the sea. In the ground, microorganisms have been found during oil drilling to a depth of 400 m. It is estimated that the total mass of all microbes living on earth is approximately 25 times the mass of all animals. For microbes' growth and multiplication, the minimum nutritional requirements are water, a source of carbon, nitrogen, and some inorganic salts. These are normally present in the natural environment. Textiles, by virtue of their characteristics and proximity to the human body, provide an excellent medium for the adherence, transfer, and propagation of infection – causing microbial species to proliferate [1,2].

In the last few years, the market for antimicrobial textiles has shown double digit growth. This growth has been fuelled by the increased need of consumers for fresh, clean, and hygienic clothing. Extensive research is taking place to develop new antimicrobial finishes. This paper reports, in detail, the

role of textiles in microbial propagation, the mechanism of antimicrobial activity, and the principles of antimicrobial finishing of textiles.

Bacteria, both pathogenic and odour-causing, interact with fibres in several phases including the initial adherence, subsequent growth, damage to the fibres, and dissemination from them. The attachment of bacteria to fabrics is dependent upon the type of bacteria and the physicochemical characteristics of the fabric substrate. Microbial adherence is also affected by the substrate and bacterial cell wall hydrophobicity. while the retention has been shown to depend on the duration of contact between the fabric and microbe. In general, the rougher the surface, the greater the retention [3–5].

Natural and synthetic fibres vary greatly in their responses to microbial growth. Both may act as willing substrates but the mechanism in the two cases is very different. Natural fibres are easy targets for microbial attack because they retain water readily, and microbial enzymes can readily hydrolyse their polymer linkages. Cotton, wool, jute, and flax are reported to be most susceptible to microbial attack. If 10^5 colonies in 1 ml water are applied to approximately 0.5 g cotton, after a few hours a logarithmic growth is observed and the population increases from 105 to 109 colonies. The damage caused by the fungus *Aspergillus niger* on cotton has been extensively investigated by Ucarci and Seventekin. They found that there were differences in the strength of cotton as the time, temperature, pH, and medium conditions changed. Within natural fibres too, the persistence period varied greatly [6].

Growth of microbes is slower on synthetic fibres as compared to their natural counterparts because their polymer backbone does not retain much water. However, these fibres encourage the holding of state perspiration in the interstices, wherein the microbes multiply rapidly. Foot infection, for example, has been found to be more pronounced with synthetic fibre socks than with natural fibre socks. You and Merry found that the adherence of bacteria to the fabrics increased as the content of polyester in the fabrics increased [7, 8].

Synthetic fibres also become susceptible to microbial degradation if there are finishing agents such as polyethylene and polysiloxane emulsions on these fibres. These additives allow the microorganisms to degrade the polymer into ‘chewable bites’ by utilising the acidic or basic by-products of their metabolism, thus initiating the cycle of hydrolysis. In this way, even the tough polyurethanes can be broken down. Polypropylene, nylon, and polyester fibres have all been seen to be subject to microbial attack under conducive conditions [9–11].

A matter of greater concern, however, is that the textiles not only act as substrates for microbial growth, but may also act as active agents in the propagation of microbes. At least two viruses of public health importance, namely polio and vaccinia, have been shown to persist on cotton and wool fabrics for sufficient periods of time. Viruses can persist on fabrics like cotton sheeting, terry towel, washable wool suit, polyester/cotton shirting, and nylon jersey for up to 16 h. Synthetic fibres allow a greater degree of viral persistence and transfer than cotton. When subjected to laundering, the virus gets physically removed from the fabric but is not inactivated, as it was found to be present in extracted water. Detergents that reduce the surface tension assist this physical removal. Thus, virus transfer can occur easily during normal cold laundering processes. Also, some bacteria actually continue to survive on laundered fabric as well [12,13].

Textile products can meet all such requirements for bacterial growth, resulting in a range of undesirable side effects. The presence and growth of these microorganisms can cause health problems, odours, and finally fabric deterioration. As microbes often attack the additives applied to textiles, discolouration and loss of the textile’s functional properties such as elasticity (brittleness) or tensile strength can also occur.

Among the side effects, the formation of malodour is of particular importance. When microorganisms grow, they metabolise nutrients such as sweat and soiling present in it and produce odour-causing molecules; for example the metabolism of Gram-positive bacteria *S. aureus* is believed to generate 3-methyl-2,hexanoic acid, which causes the characteristic body odour. The unpleasant odour develops when, among other things, bacteria convert human perspiration into four smelling substances such as carboxylic acid, aldehydes, and amines. The Gram-negative bacteria *P. Vulgaris* is known to be able to metabolise urea to form ammonia and is the cause of generation of odour in baby diapers [14].

Several products can be used to tackle the odour problem in textiles. The first two approaches involve either trapping the odour-causing molecules by incorporating adsorbent materials into textiles or using perfumes to mask the malodour. Such measures, however, only tackle the odour problem that is already there. Another approach is to use antimicrobials to prevent the formation of odour-causing compounds by inhibiting the growth of bacteria. In many personal care products around the world, such as underarm deodorants, antimicrobial agents such as triclosan have already been widely used with satisfactory results [15].

Kloos and Musselwhite observed the occurrence of various bacteria on human skin and their persistence after one year in the same person. They found that normal skin supports resident microorganisms, and different microorganisms are predominant on different parts of the body and on people of different age groups. Bacteria isolated from clothing were similar to those isolated from normal skin flora; for instance:

- Undershirts contained *Staphylococcus epidermis* and coryneform bacteria, which are responsible for body odour.
- Trouser legs and pockets contained *Bacillus* and lesser amounts of *Staphylococcus epidermis* and *Micrococcus*.
- The skin of the groin, perineum, and feet contained *Staphylococcus aureus*, Gram-negative bacteria, yeast, and the fungi *Candida albicans*, which produce skin infections, as those areas are normally moist and dark [16].

The wearing of clothing coupled with factors such as contamination of skin by faeces, urine, and another body effluents and the provision by garments of moisture and darkness can increase the probable infections. Clothing in the inguinal and perineal areas soiled by urine and faeces has been found to promote the growth of *Brevibacterium ammoniagenes*, *E. coli*, and *Proteus mirabilis*, thus aggravating diaper rash and associated infections. Over 75% of foot infections are attributed to the dermatophytic fungi

Trichophyton interdigitale and *Trichophyton rubrum* isolated from socks. It was seen that simple laundering failed to eliminate these pathogens. Some microorganisms can also cause diseases directly, for example mould fungus of the *Aspergillus* type, which can produce lung disease. Some disease-causing microorganisms and insects are listed in Table 1.

Table 1. Microorganisms and the diseases caused by them.

Microorganism	Disease or conditions caused
Gram-positive bacteria	
Staphylococcus aureus	Pyrogenic infections
Staphylococcus epidermis	Body odour
Cornybacterium ditheroides	Body odour
Brevibacterium ammoniagenes	Diaper rash
Streptococcus pneumoniae	Bacterial pneumonia
Gram-negative bacteria	
Escherichia Coli	Infections of urinogenital tract
Pseudomonas aeruginosa	Infection of wounds and burns
Proteus mirabilis	Urinary infections
Fungi	
Candida albicans	Diaper rash
Epidermothyton floccosu	Infections of skin and nails
Trichophyton interidigitale	Athletes' foot
Trichophyton rubrum	Chronic infection of skin and nails
Aspergillus niger	Damage cotton
Viruses	
Poliomyelitis visum	Poliomyelitis
Vaccinia virus	Local disease induced by vaccination against smallpox
Protozoa	
Trichomonas vaginalis	Vaginal infections

Microbial growth increases with increasing moisture and repeated laundering of textiles, and is maximal at neutral pH values (7–8). Bacteria, except the phototropic species, grow well in darkness. They are sensitive to UV light and other radiation. Exposure to light can bright about pigment production, which may cause coloured stains on fabric.

Some proposed mechanisms for microbial degradation of cotton are as follows:

- The secondary wall of cellulosic fabric may be directly damaged by fungal hypha (a thread like element of fungus), and then fungus starts growing inside the lumen.
- In some fibres, hypha penetrates the lumen without breaking the outside surface. Fungal hypha is coarser (5 μm) than the cotton pore (16 A^{o}) or even NaOH swollen pores (40–50 A^{o}).
- Bacterial decomposition of cellulose takes place from outside to inside, but they cannot digest cellulose directly. Cellulolytic microorganisms secrete enzymes which make cellulose soluble; this is followed by the diffusion of microbes inside the cell.
- Carbon heterotopy types of bacteria degrade polysaccharide chains into shorter ones which are eventually hydrolysed to shorter oligomers and then finally to cellobiose and D-glucose.

As a result of enzymatic degradation, the strength of cotton decreases by about 34% in 3–5 days at 40 ^{o}C.

Different terms are used in practice, namely 'bactericide', 'bacteriostatic', 'fungicide', 'fungistatic', 'biocide', and 'biostatic'. When a product has a negative influence on the validity of a microorganism, it is generally termed an antimicrobial. When the bacteria are killed, the suffix '-cide' is used, and when only the growth is stopped is the suffix '-static' used.

Antimicrobial agents act in various ways. The main modes of action are:

(i) protein coagulation;
(ii) disruption of cell membranes resulting in exposure, damage, or loss of the contents;
(iii) removal of free sulphydryl groups essential for the functioning of enzymes; and
(iv) substrate competition. A compound resembling the essential substrate of the enzyme diverts or misleads the enzymes necessary for the metabolism of the cell and causes cell death.

Microorganisms contain a semi-permeable cell wall which maintains the integrity of cellular contents. Bacterial agents cause the rupture of this cell membrane and damage the cells. Bacteriostatic agents only prevent the multiplication of bacteria, which may however remain alive, by inhibition of the synthesis of cell walls, alteration of cytoplasmic membrane permeability, alteration of the physical and chemical states of proteins and nucleic acids, inhibition of enzyme action, and inhibition of protein and nucleic acid synthesis. A chemical that is bactericidal at a particular concentration may only be bacteriostatic at a higher dilution.

Leaching type antimicrobial agents

The vast majority of antimicrobial products work by leaching, that is, moving from the surface on which they are applied and entering the microorganism, poisoning it, and disrupting a life process or causing a lethal mutation. The dosage of antimicrobial agent used is critical for efficiency. If too little of the compound is used, then the microbe is not controlled and can adapt. However, if too much of it is used then it can harm other living things too. This type of product also has a limited durability and has the potential to cause a variety of other problems when used in garments. The chemical may affect the normal skin bacteria, cross the skin barrier, and/or cause rashes and other skin irritations in users.

Bound type antimicrobial agents

Another set of antimicrobials with a completely different mode of action is one that bonds molecularly to the textile. This product makes the substrate surface antimicrobially active and works by rupturing the cell membrane of the microorganism when it comes into direct contact. These give durable antimicrobial properties to textiles.

Antimicrobial agent based on silver

Silver kills bacteria by strangling them in a warm and moist environment [17, 18]. Highly bioactive silver ions bind with proteins inside and outside bacterial cell membranes, thus inhibiting cell respiration and reproduction. Silver is 3–4 times more active at pH 8 than at pH 6. Silver products are effective

against bacteria but not as effective against other organisms like fungi, mould, and mildew; they can be used with polyester where many other products cannot. Alginate and chitosan have also been used to make novel antimicrobial materials in combination with silver [19].

Various techniques have been explored to attach silver to textile materials. To prepare antimicrobial fabrics suitable for sterilisation of air, cellulose was grafted with acrylic acid and treated with silver nitrate to bind the silver ions to the COOH group of graft copolymer [20]. To develop a durable finish on wool, it was treated with a complexing agent such as tannic acid or ethylene diamine tetra acetic dianhydride (EDTAD). Wool thus treated can react easily with copper and silver and inhibit the propagation of *S. aureus* and intestinal bacteria effectively. Deposition or interstitial precipitation of tetrasilver tetroxide crystals within the interstices of fibres, yarns, and/or fabrics has also been reported in a US patent [21].

Nano silver

Nano silver is a powerful and natural antimicrobial agent that has been proven highly effective in fighting a whole range of microbes. Acting as a catalyst, it reportedly disables the enzyme that one-celled bacteria, viruses, and fungi need for their oxygen intake without causing corresponding harm to human enzymes or other parts of the human body chemistry. The result is the destruction of disease-causing organisms without any detrimental effects on the surrounding human tissue.

Facts about silver

- NASA uses silver in its water purification systems for the space shuttle.
- Silver kills over 650 different types of bacteria
- The Romwater in silver vessels.
- American settlers put and stored silver coins in milk containers to prevent spoilage.

How does nano silver work?

Antimicrobial mechanism of nano-silver

- Nano silver is presumed to exert its antimicrobial effect through the dual mechanisms of denaturation and oxidation.

Denaturation

- The essential structure of the enzyme that produces oxygen seems to get disconnected by the catalytic function of silver.

Oxidisation

- Silver nano particles generate reactive oxygen in the air or in the water, which in turn destroy cell wall membranes of bacteria.

Nano silver versus other antibiotics

Effective but harmless

- Silver attacks bacteria by either denaturation or oxidisation. For these reasons, bacteria cannot build resistance against silver.
- As human cells are a tissue type, they are unaffected by these actions.

Permanent solution

- Unlike most antibiotics, which are consumed while destroying bacteria, silver remains unconsumed while constantly working as a catalyst.

Materials

Fabrics

For this study, 96 × 52 plain-woven cotton fabric (110.27 gm/m^2 varieties) was used. Warp and fill yarns are 34^S and 32^S respectively.

Tensile strength warp	55 kgf
Bending length warp	3 cm
Bending length weft	2 cm
DCRA warp	55°
DCRA weft	60°
WCRA warp	56°
WCRA weft	54°

Chemicals

- Sodium hydroxide
- Sodium carbonate
- Enzyme
- Hydrogen peroxide
- Sodium meta silicate
- Diammonium phosphate
- Non-ionic wetting agent
- Common salt

Antimicrobial agents used

- Commercial Product A (Sanitized® T 27-22 silver)
- Commercial Product B (Sanitized® T 25-25 silver)

Characteristics of Product A (Satinized® T27-22 silver)

- Composition: Silver chloride and titanium chloride
- pH (20 °C): 6.3
- Ionogenicity: Non-ionogenic
- Density at 20 °C: 0.8–1.0 gm/cm^3
- Appearance: White to light grey suspension
- Solubility: Mixable with water
- Temp. stability: Up to 190 °C
- Compatibility: Compatible with other textile chemicals such as binder, fluorocarbons, softeners, and other finishing auxiliaries.
- Fastness: Excellent wash, dry-cleaning, ironing, and perspiration resistance and light-fastness.

Characteristics of Product B (Satinized® T25-25 silver)

- Composition: Silver salt
- pH (20 °C): 6.5–7.5
- Ionogenicity: Non-ionogenic
- Density at 20 °C: 1.0 $\pm$ 0.05 gm/cm^3
- Appearance: Yellow dispersion
- Solubility: Mixable with water
- Temp. stability: Up to 190 °C
- Compatibility: Compatible with other textile chemicals such as binder, fluorocarbons, softeners, and other finishing auxiliaries.

– Fastness: Excellent wash, dry-cleaning, ironing, and perspiration resistance and light-fastness.

Auxiliaries used

- Vinyl alcohol
- Glyoxal
- Methanol
- Acetic acid
- Potassium per sulphate (PPS)
- PVOH polymer
- Magnesium chloride ($MgCl_2 6H_2O$)
- Citric acid
- Appretan N 92111 (Binder)

Methods

Preparation of fabric

a) Desizing. The grey fabric is desized with 5 gpl enzyme and 10 gpl common salt at 60 °C for 2 h.

b) Scouring. The desized fabric is treated with 2.5% sodium hydroxide, 1.5% sodium carbonate and 0.5% NP – 100 at the boil for 6 h.

c) Bleaching. The scoured fabric is bleached with 1% H_2O_2 (50%) at 80 °C for 1 h.

Preparation of PVOH polymer

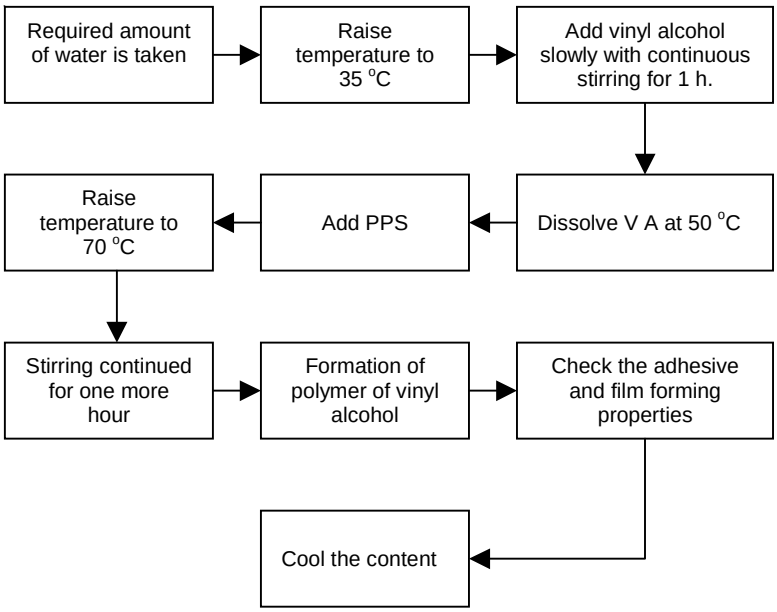

Figure 1. Preparation of PVOH polymer

Application of antimicrobial agents

Treatment with commercial Product A (Sanitized® T 27-22 silver)

The pre-scoured and bleached cotton fabric was padded separately with different concentrations of mixture solution containing various concentrations of commercial Product A (Sanitized® T 27-22 silver) (5 gpl, 10 gpl, 15 gpl, 20 gpl, and 25 gpl), PVOH (5 gpl, 7.5 gpl, and 10 gpl) and 100 gpl glyoxal/ 65 gpl Appretan N 92111 (binder), keeping 65% expression. The padded fabric samples were then dried at 80–85 °C to maintain the residual moisture content of 8–10%. The dried fabric samples were cured at various temperatures: 140 °C, 150 °C, and 160 °C for periods of 1, 2, and 3 mins.

Treatment with commercial Product B (Sanitized® T 25-25 silver)

The pre-scoured and bleached cotton fabric was padded separately with different concentrations of commercial Product B (Sanitized® T 25-25 silver) (5 gpl, 10 gpl, 15 gpl, 20 gpl, and 25 gpl), PVOH (5 gpl, 7.5 gpl, and 10 gpl), and 100 gpl glyoxal/ 65 gpl Appretan N 92111 (binder), keeping a 65% expression. The padded fabric samples were then dried at 80–85 °C to maintain the residual moisture content of 8–10 %. The dried fabric samples were cured at various temperatures: 140 °C, 150 °C, and 160 °C for periods of 1, 2, and 3 mins.

Testing and analysis

Measurement of tensile strength

The tensile strength was measured as per IS: 1969–1968 using Instron 1122. We measured the tensile strength of treated and untreated fabric warp wise. Strips of 20 × 5 cm were taken for tensile strength testing.

Measurement of bending length

The bending lengths of the samples in both warp and weft directions were measured as per IS: 6490–197 I using a Shirley stiffness tester.

Measurement of dry and wet crease recovery angles

Dry and wet crease recovery angles of untreated and treated samples were measured using a Shirley crease recovery tester.

Antimicrobial activity

After confirming the antimicrobial activity of finished fabrics, the next step was to determine their minimum strength, which could inhibit microbial growth. For that we determined the minimum inhibitory concentration (MIC) of the finished fabric. To evaluate the antibacterial activity, AATCC test method 90-1970, the agar plate method, was employed.

Preparation and sterilisation of media suitable for growth

Bacteria

Nutrient Agar. Agar is the most commonly used medium for various microbial works. It contains peptone, which acts as a major source of nitrogen and carbon. It also acts as a source of trace elements, inorganic salts, and growth factors. Meat extract in the medium acts as a source of inorganic salts and growth factors. Agar-agar powder helps to make the medium solid. Nutrient agar is also mainly used for isolation and cultivation of various common micro-organisms like *E. coli, S. aureus,* and *B. subtilis*.

Chemical composition of nutrient agar:

Peptone- 1 gm
NaCl - 0.5 gm
Meat extract - 0.3 gm
Distilled water - 100 ml
Agar-agar - 2.5 gm
pH - 7.2

Table 2. Properties of commercial Product A (Sanitized® T 27-22 silver) treated cotton fabric.

PVOH (gpl)	Nano silver (gpl)	Curing temp. (°C)	Curing time (mins)	Tensile strength (kgf)	Bending length (cm)		DCRA (°)		WCRA (°)		Zone of inhibition (mm)	
				Warp	Warp	Weft	Warp	Weft	Warp	Weft	Gram +ve	Gram –ve
05	05	140	1	52	6.3	4.5	98	96	93	90	24	14
			2	51.5	6.4	4.5	101	99	97	93	24	14.2
			3	51	6.7	4.6	115	99	110	95	24	14.5
		150	1	51.6	6.4	4.5	116	99	111	93	24.3	14.2
			2	51	6.5	4.5	117	110	113	96	24.3	14.3
			3	50.6	6.7	4.6	118	102	113	99	24.3	14.3
		160	1	49.9	6.6	4.6	120	110	115	105	24.5	14.5
			2	49.6	6.6	4.6	122	113	117	106	24.5	14.6
			3	48.4	6.7	4.7	124	109	119	108	24.5	14.8
	25	140	1	52	6.7	4.7	110	108	105	103	25	15
			2	51.3	6.7	4.7	111	108	106	104	25	15.2
			3	51	6.8	4.8	113	109	108	104	25	15.5
		150	1	51.1	6.7	4.7	111	108	100	104	25.1	15.5
			2	50.7	6.7	4.8	111	109	110	105	25.2	15.6
			3	50.2	6.8	4.8	113	109	111	106	2.53	15.6
		160	1	49.8	6.7	4.8	114	112	109	107	25.5	15.6
			2	49.5	6.7	4.8	112	110	106	105	25.5	15.7
			3	49.2	6.8	4.9	105	110	100	99	25.5	16
10	05	140	1	49.6	6.8	4.7	122	110	116	105	26.5	16.2
			2	49.4	6.8	4.7	122	111	116	110	26.5	16.3
			3	49.1	6.9	4.8	123	112	117	117	26.5	16.5
		150	1	49.3	6.8	4.7	112	110	116	112	26.6	16.5
			2	49	6.9	4.8	112	108	111	110	26.6	16.6
			3	48.8	7.0	4.8	122	106	109	109	26.6	16.6
		160	1	49.27	6.8	4.8	114	106	109	101	27.5	16.8
			2	48.7	6.9	4.8	112	105	106	101	27.5	16.9
			3	48.51	7.0	4.9	110	104	105	101	27.5	17
	25	140	1	49.2	6.8	4.9	120	112	115	107	28	17
			2	48.83	6.8	4.9	118	110	111	105	28	17.2
			3	48.61	6.9	5.0	115	103	110	98	28	17.5
		150	1	48.7	6.8	4.9	110	113	116	107	28.2	17.5
			2	48.54	6.9	4.9	117	110	112	102	28.2	17.5
			3	48.4	7.0	4.8	111	109	110	100	28.2	17.5
		160	1	48.61	6.8	5.0	110	106	105	108	29	17.5
			2	48.52	6.9	5.0	107	104	102	98	29	17.7
			3	48.4	7.0	5.1	105	95	100	90	29	18

All the ingredients were accurately weighed to give the above composition and dissolved in distilled water. The pH value was adjusted to 7.2, and 2.5 gm of agar-agar was added to 100 ml of nutrient broth. The medium was sterilised by autoclaving, poured into petri plates aseptically, and then allowed to solidify.

Scanning electron microscopy (SEM)

The antimicrobial finished samples were observed visually and the topography or morphology of the fabric samples was analysed using high resolution SEM with suitable accelerating voltage and magnification (× 900).

Operating voltage : 4 KV
Vacuum : below 5 Pa

Results and discussion

The warp tensile strength, bending length (warp and weft), dry crease recovery angle (warp and weft), wet crease recovery angle (warp and weft), and zone of inhibition of Gram-positive as well as Gram-negative bacteria of cotton fabric finished with Sanitized® T 27-22 silver & Satinized® T 25-25 silver are shown in Tables 2 and 3 respectively.

From Table 2, it is clear that the higher the concentration of PVOH, the greater the bending length and crease recovery angle. The higher the curing temperature and time, the better the crease recovery and bending length, and the lower the tensile strength. The higher the concentration of commercial Product A (Sanitized® T 27-22 silver), the greater the zone of inhibition. Here, the minimum zone of inhibition for Gram-positive bacteria (*S. aureus*) is 24 mm and the maximum

Table 3. Properties of commercial Product B (Sanitized® T 25-25 silver) treated cotton fabric.

PVOH (gpl)	Nano silver (gpl)	Temp. of curing (°C)	Curing time (mins)	Tensile strength (kgf)	Bending length (cm)		DCRA (°)		WCRA (°)		Zone of inhibition (mm)	
				Warp	Warp	Weft	Warp	Weft	Warp	Weft	Gram +ve	Gram –ve
05	05	140	1	52	6.3	4.5	98	96	93	90	24	14
			2	51.5	6.4	4.5	101	99	97	93	24.1	14.2
			3	51	6.7	4.6	115	99	110	95	24.2	14.4
		150	1	51.6	6.4	4.5	116	99	111	93	24.1	14.3
			2	51	6.5	4.5	117	110	113	96	24.2	14.4
			3	50.6	6.7	4.6	118	102	113	99	24.4	14.4
		160	1	49.9	6.6	4.6	120	110	115	105	24.5	14.5
			2	49.6	6.6	4.6	122	113	117	106	24.5	14.6
			3	48.4	6.7	4.7	124	109	119	108	24.6	14.8
	25	140	1	52	6.7	4.7	110	108	105	103	24.8	15
			2	51.3	6.7	4.7	111	108	106	104	24.9	15.3
			3	51	6.8	4.8	113	109	108	104	25	15.4
		150	1	51.1	6.7	4.7	111	108	100	104	25.2	15.2
			2	50.7	6.7	4.8	111	109	110	105	25.3	15.4
			3	50.2	6.8	4.8	113	109	111	106	25.4	15.5
		160	1	49.8	6.7	4.8	114	112	109	107	25.5	15.5
			2	49.5	6.7	4.8	112	110	106	105	25.6	15.7
			3	49.2	6.8	4.9	105	110	100	99	25.7	16
10	05	140	1	49.6	6.8	4.7	122	110	116	105	26.3	16.2
			2	49.4	6.8	4.7	122	111	116	110	26.4	16.3
			3	49.1	6.9	4.8	123	112	117	117	26.6	16.5
		150	1	49.3	6.8	4.7	112	110	116	112	26.5	16.3
			2	49	6.9	4.8	112	108	111	110	26.6	16.5
			3	48.8	7.0	4.8	122	106	109	109	26.8	16.7
		160	1	49.27	6.8	4.8	114	106	109	101	27.2	16.8
			2	48.7	6.9	4.8	112	105	106	101	27.3	16.9
			3	48.51	7.0	4.9	110	104	105	101	27.3	17
	25	140	1	49.2	6.8	4.9	120	112	115	107	27.8	17.1
			2	48.83	6.8	4.9	118	110	111	105	27.9	17.2
			3	48.61	6.9	5.0	115	103	110	98	28	17.4
		150	1	48.7	6.8	4.9	110	113	116	107	27.9	17.2
			2	48.54	6.9	4.9	117	110	112	102	28.2	17.3
			3	48.4	7.0	4.8	111	109	110	100	28.5	17.4
		160	1	48.61	6.8	5.0	110	106	105	108	29	17.5
			2	48.52	6.9	5.0	107	104	102	98	29.3	17.8
			3	48.4	7.0	5.1	105	95	100	90	29.5	18.6

zone of inhibition is 29 mm. For Gram-negative bacteria (*E. coli*), the minimum zone of inhibition is 14 mm and the maximum is 18 mm.

From Table 3, it is clear that the higher the concentration of PVOH, the greater the bending length and crease recovery angle. The higher the curing temperature and time, the better the crease recovery and bending length, and the lower the tensile strength. The higher the concentration of commercial Product B (Sanitized® T 25-25 silver), the greater the zone of inhibition. Here, the minimum zone of inhibition for Gram-positive bacteria (S. aureus) is 24 mm and the maximum zone of inhibition is 29.5 mm. For Gram-negative bacteria (E. coli), the minimum zone of inhibition is 14 mm and the maximum is 18.6 mm.

Zone of inhibition

The test for the zone of inhibition was carried out on petri plates as shown in the diagram below. Two types of bacteria, Gram-positive and Gram-negative, were used for this test. It was observed that the zone of inhibition of Gram-positive bacteria was greater compared to that for Gram-negative bacteria.

Scanning electron microscopy (SEM)

The antimicrobial finished samples were observed visually and the topography or morphology of the fabric samples was analysed using high resolution SEM with suitable accelerating voltage and magnification (´ 900). The photographs are shown in Fig. 3. From this figure, it is clear that continuous polymer film has formed on the finished fabric. This improves the durability of the antimicrobial effect.

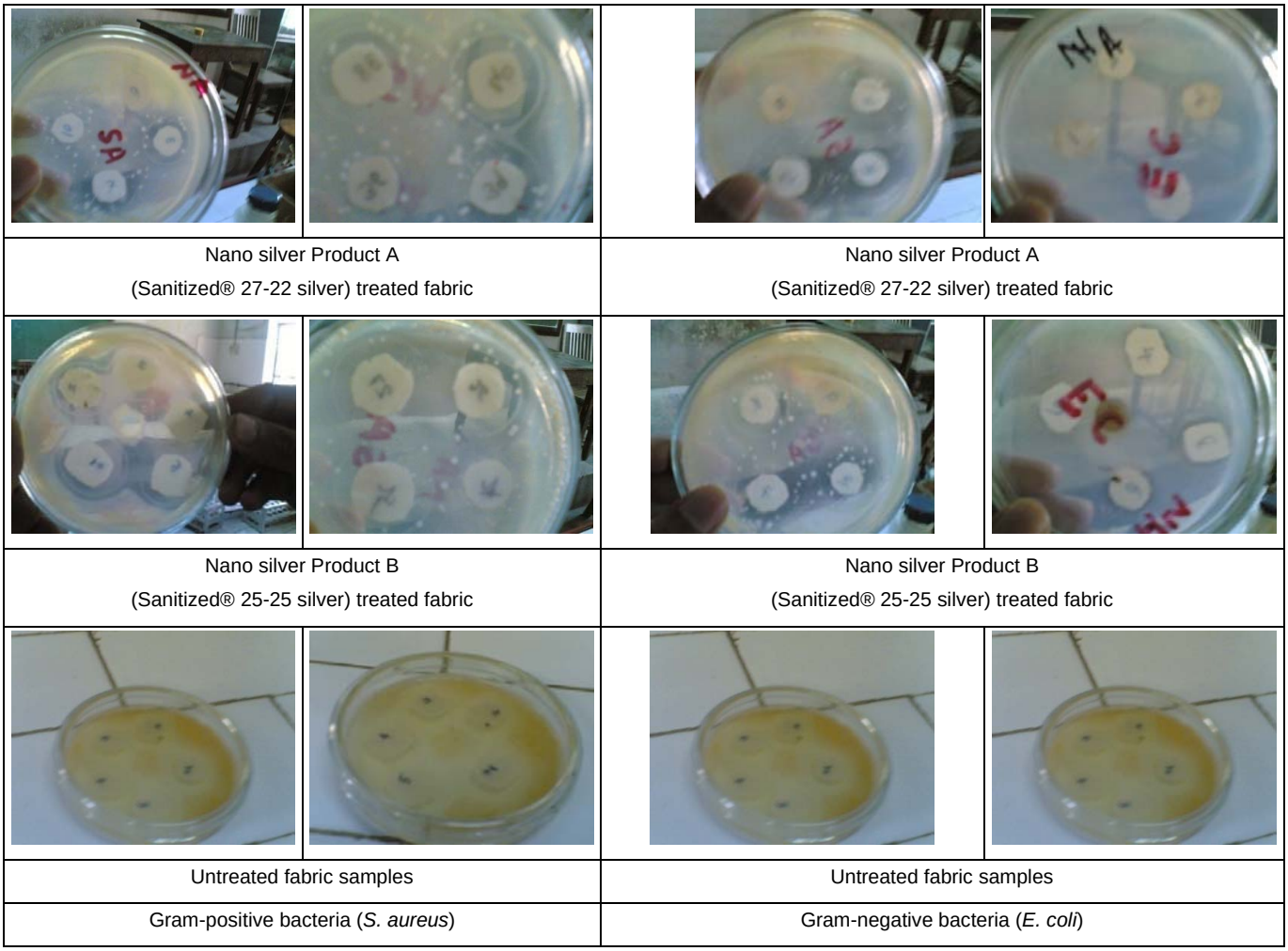

Figure 2. Zones of inhibition

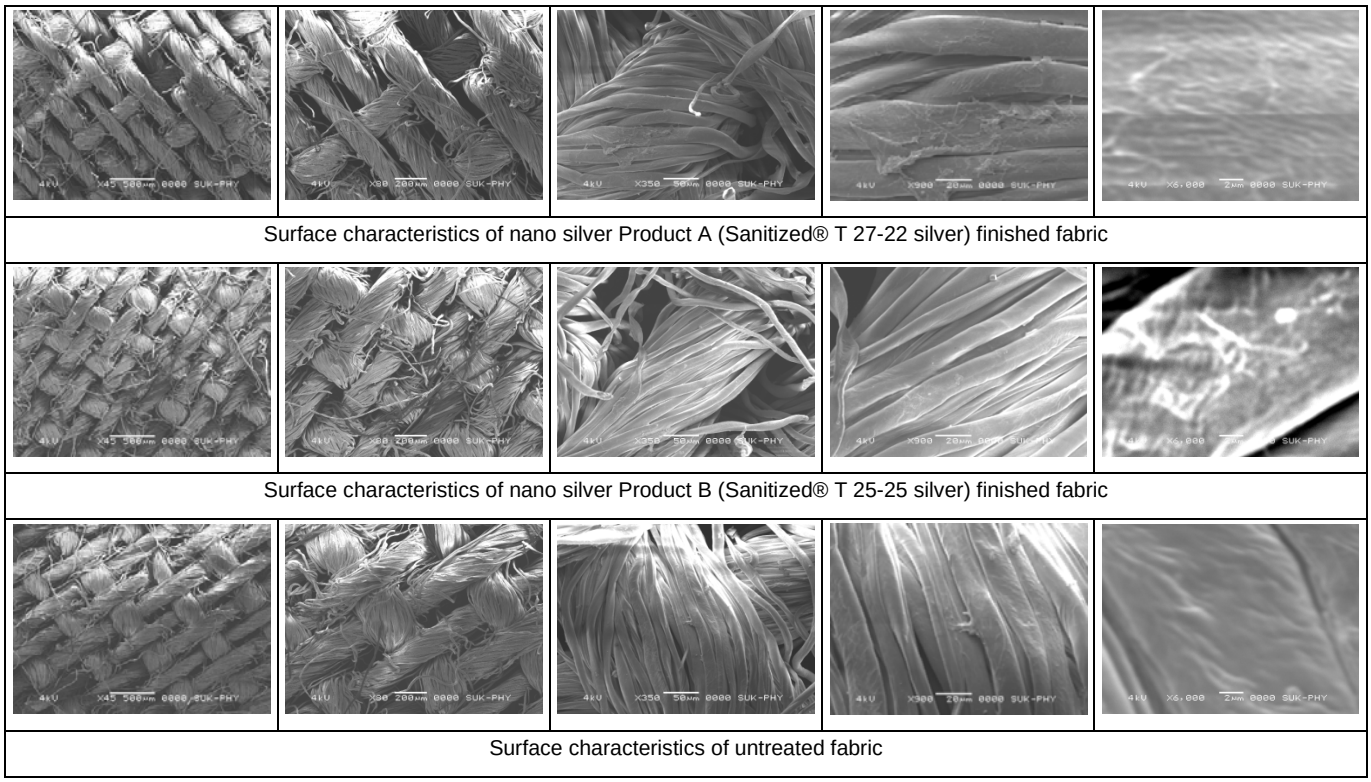

Figure 3. Scanning Electron Microscope photographs.

Conclusions

Nano silver can be used effectively as an antimicrobial agent for cotton. The higher the concentration of antimicrobial agent, the larger the zone of inhibition in the cases of both Gram-positive and Gram-negative bacteria. SEM study of antimicrobial-finished fabric reveals that a continuous polymer film has been formed on the fabric. The concentration of PVOH controls the bending length and crease recovery angle. The higher the concentration of PVOH, the greater the bending length and crease recovery angle. Curing temperature and time have profound impacts on the tensile strength. The higher the curing temperature and time, the lower the tensile strength.

In the case of commercial Product A (Sanitized® T 27-22 silver) treated cotton fabric, the zone of inhibition of Gram-positive bacteria was a minimum of 24 mm and a maximum of 29 mm, while for Gram-negative bacteria the minimum was 14 mm and the maximum 18 mm.

In the case of commercial Product B (Sanitized® T 25-25 silver) treated cotton fabric, the zone of inhibition of Gram-positive bacteria was a minimum of 24 mm and a maximum of 29.5 mm, while for Gram-negative bacteria the minimum was 14 mm and the maximum 18.6 mm.

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