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Antimicrobial Effect of Additive Silver Nanoparticles to Paints for Reducing the Risk of Cross-Contamination

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Authors' contributions

This work was carried out in collaboration between both authors. They designed the study, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Paints are mainly used to protect metal structures from rusting and object from adverse effects of weather and sun, in addition to decoration. Most paints are either oil-based or water-based and both have distinct advantages. It can be applied as a solid, a gaseous suspension (aerosol) or a liquid. The increasing demand for new antimicrobial paints is rising recently due to the important need to avoid the spreading of infections mainly caused by harmful microorganisms. The antimicrobial additive can be defined as the additive compound that can resist or prevents the growth of harmful microbes. In this connection, a number of critical factors should be considered in selecting the additive antimicrobials to paints. These factors include safe from adverse impacts on human health and environment, antimicrobial efficiency, achieve a broad spectrum of microbial control, low percentage of the antimicrobial additive, ease of handling, fast and long-acting, migration capability, chemical stability, cost-effective and maintaining the properties of the product and its components. In the case of edible coatings which provide a unique opportunity to control microbial and oxidative changes in human ready-to-use food products, suitable safe materials and

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active agents for different cases should be applied. To make the traditional paints resistant to pathogenic microorganisms, it is of importance to include several antimicrobial additives, such as silver and zinc ions during the manufacturing process. Silver is a widely used technology in the world, especially in its nano-particle form due to its suitability for deployment in a broad range of materials and applications and its broad spectrum performance. This durable treatment will provide to a large extent effective protection against harmful fungi, bacteria, viruses and consequently helping to minimize staining and material degradation on any surface it is applied to. These antimicrobial paints (APs) can be used in places that harbor pathogenic microorganisms such as hospitals, schools, care homes, kitchen areas, dental and veterinary practices and food production factories. In these places, APs can be applied to contact surfaces within these environments, such as door handles, light switches, flooring, elevator buttons, and bathroom in order to reduce the risk of cross-contamination.

Keywords: Antimicrobial activity; silver nanoparticles; biofilm; transmission electron microscopy; target site; silver ions.

ABBREVIATIONS

AgNP : Silver nanoparticles.
APs : Antimicrobial paints.
MNPs : Metal nanoparticles.
TEM : Transmission electron microscopy.
EFTEM : Energy-filtering transmission electron microscopy.
SEM : Scanning electron microscopy.
MRSA : Mecicillin resistant Staphylococcus aureus.

1. INTRODUCTION

One of the major problems in industrial field is microbial invasion of surfaces, which result in health hazard in medical devices due to biofilm formation which represent a challenge in the health-care industry [1,2]. Approaches of researchers include embedding antimicrobial agents directly to surfaces or through the addition of these agents to paints. Various tests can be applied to these surfaces to ensure the efficacy of this treatment. Antimicrobial paint additives include a wide range of commercial materials such as chlorothalonil (CTL), zinc pyrithione (ZPT), 3-iodopropargyl-n-butylcarbamate (IPBC), 2-n-octyl-4-isothiazolin-3-one (OIT), 4,5-dichloro-2-(n-octyl)-4-isothiazolin-3-one (DCOIT) and carbendazim (CBZ), in addition to other antimicrobial additives in different forms, such as cationic silane, thiabendazol, silver technology, zinc pyrithion and folpet [3,4]. In this connection, preservative materials should be added to paints to suspend the growth of microorganisms and other lifeforms during storage and to protect these materials from destruction. Marine and offshore protective paints are used to reduce the growth of marine microorganisms and associated biofilms that degrade steel structures. The increasing interest of using nano-structured materials in the development of paints is increasing especially of nano-structured additives to paint that are able to confer antimicrobial property [5]. Nanotechnology is one of the important technologies in applications that deal with anti-microbial additives and reduce toxicity in many industrial fields. For example, inks that have anti-microbial properties, they protect humans and animals from diseases caused by pathogens. Also, pigments treated with nano-particles of zinc oxide reduce the microbial activities significantly compared to standard inks. In addition, these additives do not affect the chemical properties of the surfaces covered with acrylic materials [6]. Many investigators described an environmentally friendly chemistry approach to synthesize metal nano-particles (MNps) embedded manufacturing process. Paint technology has advanced many folds in recent years to achieve this target. This durable treatment will provide to a large extent effective protection against harmful fungi, bacteria and viruses. Coating of surfaces with silver nanoparticle paints showed effective antimicrobial properties, by killing both Gram-positive and Gram-negative microbial bacterial pathogens namely *Staphylococcus aureus* and *Escherichia coli* respectively. For nano-paints, it is recommended to pay special attention to occupational health aspects for avoiding dust generation during production, maintenance and recycling. It is equally important to explore the potential benefits during early stages of innovation using a safe-by-design approach to modify the nanomaterial and the paint formulation in order to avoid risks. Many studies reported the use of nano-particles (NPs) as antibacterial additives to paints [7,8]. Since silver possesses natural antibacterial properties, the more active prepared silver nano-particles (AgNPs) are selected to attain this property

[9-11]. Many investigators reported the incorporation of NPs to paints [12], medical devices [13] and other commercial products which resulted mainly in health protection. The aim of this review article is to highlight the antimicrobial mechanisms of additive silver nanoparticles to paints for reducing the risk of cross-contamination.

2. MECHANISMS OF ADDITIVE ANTIBACTERIAL NANO-PARTICLES TO PAINTS

Few studies were reported concerning the mechanisms through which nano-particles (NPs) induce their detrimental damage to bacterial cells. These effects are mainly induced on deoxy ribonucleic acids (DNA) and/ or bacterial proteins found in cell membranes or inside bacterial cells. Silver in its nano-structure represents the most commonly used antibacterial agent in many fields including antibacterial additives to paints that reduce the contamination of harmful microorganisms [14], in addition they showed antiviral activity against viruses such as HIV infected cells [15]. Since more studies have proven the antibacterial activity of silver against a wide spectrum of microorganisms, it is being used as antibacterial agent in a large number of medical applications. This considers appeared that AgNPs were in addition centered on the same structures and molecules in bacterial cells.

The mechanism of antimicrobial action of silver ions is mainly due to their interaction with thiol groups in cysteine residues in the bacterial protein chain Fig 1. This action occurred to the negligible electro-negativity difference between silver and sulfur ions forming a covalent bond [16,17]. Normally the disulfide bond (-S-S-) is formed through the oxidation between two thiol groups of cysteine residues at protein chain, participates to the tertiary structure of a protein. In case of forming a covalent bond between silver and sulfur ions in the presence of antimicrobial agent, the bacterial protein structure and folding alter and consequently changing the active sites of the enzyme resulting to its inhibition and bacterial inactivation [16].

Dibrov et al., [18] reported that the antibacterial activity of silver ions is not the result of interaction with specific target site in *Vibrio cholera*, but Ag ions attack several sites. Yakabe et al., [19] indicated that silver ion interacts with bases in bacterial nucleic acids rather than with the phosphate group. In another study, Yamanaka et al., [20] reported that silver ions penetrated inside *E. coli* cells and various stages of cell death were detected using energy-filtering transmission electron microscopy (EFTEM). These authors concluded that silver ions penetrated through ion channels without damaging cell membranes. This action results in denaturing ribosome and proteins essential to adenosine triphosphate (ATP) formation, followed by suppressing enzymes expression. This point of view is in contrast to other studies reported that silver ions primarily affect membrane-bound enzymes functions such as those in the respiratory chain through their binding to thiol groups [21]. In a reported study using Transmission electron microscopy (TEM) to show the morphological changes in two Gram-positive and Gram-negative bacteria namely *Staphylococcus aureus* and *Escherichia coli* respectively after Ag^+ treatment indicated that there is a shrunk and detached cytoplasm membrane from the cell-wall [22]. These authors also reported the presence of electron dense granules around and inside the bacterial cell wall after silver ions treatment in disagreement with the results obtained by Jung et al., [8] who indicated that silver ions react mainly with phosphorus and sulfur. These authors concluded that silver ions entered the cells and combined with their components containing sulfur as they found that *S. aureus* had large amounts of phosphorus in the condensed region in the middle of the bacterial cells. They mentioned that the entrance of silver ions into bacterial cells may lead to deposition of proteins and consequently the small electron-dense granules outside the electron-light region can be combined with Ag^+ causing the deposition of proteins. Different postulations were suggested in the literature to elucidate the changes occur to bacterial cell components after silver nano-particles(AgNPs) treatment using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) which are highly versatile methodologies for 2D and 3D nano-materials characterization. The target sites reported of AgNPs action on bacterial cells by different investigators are shown in Table 1.

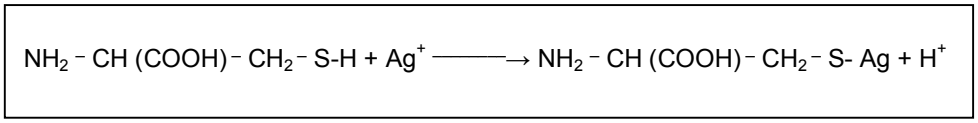


Fig. 1. Reaction of amino acid cysteine with silver ion

Table 1. Target sites of the action of AgNPs on bacterial cells

Microorganism	Target site	Reference
Escherichia coli	Cell-membrane	Sondi and Salopek-Sondi, 2004; Morones et al., 2005; Lok et al., 2007 [23-25]
E.coli	Sulfur and phosphorus containing molecules	Pal et al., 2007 [26]
E.coli, Staphylococcus aureus, Listeria monocytogenes	Cell-membrane & Sulfur and phosphorus containing molecules	Raffi et al., 2008; Fernandez et al., 2008 [11,27]
Recombinant bioluminescence E.coli	Cell-membrane	Hwang et al., 2008 [28]
E.coli, Staph. aureus	Sulfur and phosphorus containing molecules	Panacek et al., 2006 [29]
Bacillus subtilis, Staph. aureus, E.coli, Staph. epidermidis	Cell-membrane	Paula et al., 2009 [30]

The morphological changes occurred in the bacterial cell wall involve pits formation and leakage of cell contents leading to cell lysis. Pits formation leads to increase the membrane permeability and improper transport through the plasma membrane [23]. In this connection, Amro et al., [31] also reported the presence of pits formation in the bacterial cell wall leading to an increase of membrane permeability in *E.coli* and the release of lipopolysaccharide molecules (LPs) and membrane proteins. The same mechanism is supported by Raffi et al., [11] who indicate that the structure of cell-membrane is highly affected during the treatment of silver nanoparticles (AgNPs), however they failed to elucidate the mechanism of LPs release from the bacterial cell. Morones et al., [24] indicated that bactericidal silver nanoparticles located on the bacterial membrane may bind to the carbamate ($CH_2NO_2^-$) group of the amino acid, as shown in Fig. 2.

Panacek et al., [29] suggested that the mechanism involves the attachment of nanoparticles to the surface of cell-membrane causing disturbance to the respiration and permeability functions. Many investigators reported that there is no indication until now to find the exact pathway(s) through which the nanoparticles introduce their antibacterial effect. They postulated that this property occur either through the interaction of these particles with cell components or through the released ions or both ways. Song et al., [7] reported that the presence of different morphological structures in various types of treated Gram positive and Gram negative bacteria by AgNPs. Thus for *E.coli* they showed separation of cytoplasm from bacterial cell wall (plasmolysis), while in case of *S. aureus*, the synthesis of cell-wall was inhibited. The only observed change in *Mycobacterium tuberculosis* was the presence of AgNPs inside the cells. Sondi and Salopek-Sondi [23] described the mechanism through which the nanoparticles are able to penetrate the bacterial cell by the changes occurred in the membrane morphology leading to the increase in membrane permeability. The released Ag ions from nanoparticles interact with sulfur-containing bacterial proteins in the membrane resulting changes of its property. The same authors reported that at biological pH values, the bacterial surface is negatively charged due to the dissociation of carboxylic and other groups in the membrane. Stoimenov et al., [32] demonstrated that the inhibitory effect of Ag ions against some bacterial species may be due to the degradation of bacterial enzymes or plasma membrane and death of bacterial cells results mainly from impaired metabolic pathways and leakage of the cytoplasmic components to their surroundings. The study reported by Hwang et al., [28] indicated that silver nanoparticles induce their antibacterial activities via the production of Ag

ions in bioluminescent bacteria. Other investigation described the antibacterial mechanism by the formation of Reactive Oxygen Species (ROS) and superoxide radicals that target the fatty acids and initiate lipid peroxidation [33]. ROS induce their toxicity through the oxidation of sulfhydryl groups and these reactions affect the bacterial proteins and membranes functions and block DNA replication or cause mutations [34]. It is of importance that silver nanoparticles release Ag to attack pathogenic bacteria, after that the elemental Ag must be oxidized to produce Ag ions according to the following equation. Table 2 summarized the different suggested mechanisms through which additive AgNPs to paints affect harmful bacteria.

$$Ag^0 \text{ ----------} \rightarrow Ag^+ + e$$

Table 2. Summary of the suggested mechanisms through which additive silver nanoparticles to paints affect bacterial cells

Mechanism	Reference
Silver nanoparticles induced their effect on deoxy ribonucleic acid (DNA) and/ or bacterial proteins found in cell membranes or inside bacterial cells. Silver is mainly due to their interaction with thiol groups in cysteine residues in the bacterial protein chain.	Perelshtein et al., 2008 [40] Liau et al. 1997; Gupta et al. 1998 [16,17]
By forming a covalent bond between silver and sulfur ions in the presence of antimicrobial agent, the bacterial protein structure and folding alter and consequently changing the active sites of the enzyme resulting to its inhibition and bacterial inactivation.	Liau et al., 1997 [16]
The antibacterial activity of silver ions is not the result of interaction with specific target site, but Ag ions attack several sites. Silver ion interacts with bases in bacterial nucleic acids rather than with the phosphate group.	Dibrov et al., 2002 [18] Yakabe et al., 1980 [19]
Silver ions penetrated bacterial cell through ion channels without damaging cell membranes. This action results in denaturing ribosome and proteins essential to adenosine triphosphate (ATP) production, followed by suppressing enzymes expression.	Yamanaka et al., 2005 [20]
Silver ions primarily affect membrane-bound enzymes functions through their binding to thiol groups.	McDonnel and Russell, 1999 [21]
Ag^+ treatment resulted to the presence of electron dense granules around and inside the bacterial cell wall.	Feng et al., 2000 [22]
Silver ions entered the cells and react mainly with phosphorus and sulfur leading to deposition of proteins and consequently the small electron-dense granules outside the electron-light region can be combined with Ag^+ causing the deposition of proteins.	Jung et al., 2008 [8]
The morphological changes occurred in the bacterial cell wall involve pits formation and leakage of cell contents, increase the membrane permeability and improper transport through the plasma membrane leading to cell lysis.	Raffi et al., 2008; Sondi and Salopek-Sondi, 2004; [11,23]
Due to the presence of pits formation in the bacterial cell wall leading to an increase of membrane permeability and the release of lipopolysaccharide molecules (LPs) and membrane proteins.	Amro et al., 2000 [31]
Bactericidal silver nanoparticles located on the bacterial membrane may bind to the carbamate group ($CH_2NO_2^-$) of the amino acid.	Morones et al., 2005 [24]
The mechanism involves the attachment of nanoparticles to the surface of the cell-membrane causing disturbance to the respiration and permeability functions.	Panacek et al., 2006 [29]
The antibacterial mechanism was suggested by the formation of Reactive Oxygen Species (ROS) and superoxide radicals that target the fatty acids and initiate lipid peroxidation.	Cabiscol et al., 2000 [33]
ROS induce their toxicity through the oxidation of sulfhydryl groups and consequently affect the bacterial proteins and membranes functions and block DNA replication or cause mutations.	Stadtman 1990 [34]

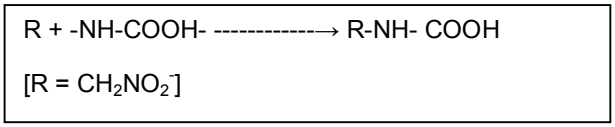


Fig. 2. Carbamate formation at N-terminal amino acid residue

Many investigators reported that AgNPs have been produced physically and chemically for a long time, however recent developments indicated the critical role of biological systems and microorganisms in the production of metal nanoparticles [35-38]. Wenhao et al.,[39] indicated the importance of AgNPs as antibacterial agent.

3. FACTORS AFFECTING THE ACTIVITY OF SILVER NANOPARTICLES TREATMENT

Panacek et al., [29] concluded that the effect of nano-silver ions on the morphology of different bacterial types depend mainly on the treatment dose, they indicated that a dose of 6.75 ug/ml was toxic for Methicillin-Resistant *Staphylococcus aureus* (MRSA) compared to a dose of 3.38 ug/ml used against *E. coli*. According to Song et al., [7], the antibacterial activity was observed against Gram negative bacteria such as *E. coli*, *Salmonella typhi* and *Pseudomonas aeruginosa* by using a dose of 1 ppm, while in case of Gram positive bacteria the used concentration was around 10 ppm indicating that the antibacterial activity depends on the type of bacteria. This observation can be elucidated by the presence thicker peptidoglycan layer in Gram positive bacterial cell-walls which resist the entrance of the nanoparticles into the cell. In accordance with this observation Morones et al., [24] support the same postulation and mentioned that higher concentration of AgNPs are required to inhibit the growth of *P. aeruginosa* and *Vibro cholera* as, compared with that required to inhibit *E. coli* and *S. typhus*. In contrast to these results, Maneerung et al., [41] reported that *E. coli* was more resistant than *S aureus* after treatment with silver nanaparticles. The *E.coli* resistance was related to the presence of lipo-polysacharide (LP) content in the cell wall. Also the study of Yoon et al.,[42] indicated that the Gram positive bacterium, *B. subtilis* was more sensitive than the Gram negative bacterium, *E.coli*. Different types of microbiological media are another factor affecting the antibacterial activity. Different antibacterial activity were recorded when Sondi and Salopek-Sondi [23] applied silver nanoparticles against *E. coli* using two methods namely agar plates and liquid medium. These authors showed that, in agar plates there is a complete inhibition in bacterial growth, however, the treatment of silver nanoparticles in liquid medium caused a delay in the growth of *E. coli*. Different shapes of silver nanoparticles were investigated by Pal et al., [26] to evaluate the antibacterial property using both previously mentioned liquid medium and agar plates. They found that truncated triangular nanoparticles had the strongest biocidal activity, compared to the spherical and rod-shaped nanoparticles. In this connection, many investigators [11,43] reported that small size nanoparticles have the highest biocidal effect compared to the large one and this is due to their large surface area capable to bind with bacterial surface. In accordance with this observation, Morones et al., [24] indicated that NPs smaller than 10nm showed the highest antibacterial activity, however Panacek et al., [29] reported that 25 nm exhibit the highest antibacterial activity. Another reported studies indicated that AgNPs is related to adsorption of Ag ions on the surface of particles and the antibacterial activities are correlated with the levels of chemisorbed Ag ions formed on the surface of the particle [25]. One of the factors affecting the efficiency of the antimicrobial activity is the agglomeration of AgNPs. These agglomerated particles induce their effect by reducing the ions release [44]. The incorporation of AgNPs into organic polymer matrix enhances greatly the release of Ag ions and preventing the aggregation of these nanoparticles. The previously mentioned authors also mentioned that the incorporation of AgNPs into molten polyamide polymer induces antibacterial against *S.aureus* and *E. coli* and this activity increased gradually as a function of time. Dowling et al, [45] reported that Ag ions release can be enhanced by the addition of trace elements such as platinum through galvanic action. Hendry and Stewart, and McHugh et al., [46,47] reported the bacterial resistance against Ag in *E.coli* and *Salmonella typhimurium* respectively, however the study of Anderson [48] claims that excess use of AgNPs can induce bacterial resistance towards these particles. Table 3 demonstrates the different factors affecting the activity of silver nanoparticles treatment on bacterial cell.

Table 3. Factors affecting the activity of AgNPs treatment on bacterial cell

Factor type	Details	Reference
Treatment dose	AgNPs treatment against bacterial cells mainly depend on the treatment dose.	Panacek et al., 2006 [29]
Type of bacteria	The antibacterial activity depends on the type of bacteria. The presence of thicker peptidoglycan layer in Gram positive bacterial cell-walls resist the entrance of the nanoparticles into the cell.	Song et al., 2006 [7]
AgNPs concentration	Higher concentration of silver nanoparticles are required to inhibit the growth of Gram positive bacteria compared with that required to inhibit Gram negative bacteria.	Morones et al., 2005 [24]
Cell-wall compostion	Gram negative bacteria (*E. coli)* are more resistant than Gram positive bacteria *(S aureus*) after treatment with AgNPs due to the presence of lipo-polysacharide (LP) content in the cell wall.	Maneerung et al., 2008 [41]
Sensitivity of bacteria towards AgNPs treatment	Gram positive bacteria (*B. subtilis)* are more sensitive than the Gram negative bacteria (*E. coli*), after treatment with AgNPs.	Yoon et al., 2007 [42]
Types of microbiological media	Different types of microbiological media are another factor affecting the antibacterial activity.	Sondi and Salopek-Sondi, 2004 [23]
Shape of AgNPs	In testing different AgNPs shapes truncated triangular nanoparticles had the strongest biocidal activity, compared to the spherical and rod-shaped nanoparticles.	Pal et al., 2007 [26]
Size of AgNPs	Small size nanoparticles have the highest biocidal effect compared to the large one and this is due to their large surface area capable to bind with bacterial surface.	Raffi et al., 2008; Castanon et al., 2008 [11,43]
Agglomeration of AgNPs	One of the factors affecting the efficiency of the antimicrobial activity is the agglomeration of AgNPs. These agglomerated particles induce their effect by reducing the ions release. The incorporation of AgNPs into organic polymer matrix (molten polyamide polymer) enhances greatly the release of Ag ions and preventing the aggregation of these nanoparticles.	Kumar and Munstedt, 2005 [44]
Bacterial resistance	Bacterial resistance against Ag can occur in Gram negative bacteria (*E.coli* and *Salmonella typhimurium*). Excess use of AgNPs can induce bacterial resistance towards these nanoparticles.	Hendry and Stewart, 1979; McHugh et al., 1975; Anderson, 2008 [46-48]

4. IMPORTANCE OF THE ADDITION OF ANTIMICROBIAL AGENTS TO PAINT

In recent years, paint technology has advanced many folds to achieve protection against invading of harmful microorganisms and also to avoid deteriorating the painted surfaces. Paint applied for interior or external use can be categorized into waterborne and solvent-borne and both should have two functions namely protection and decoration. Contamination of paint by microbial growth in either wet state or dried film can destroy these functions, leading to both physical and aesthetic degradation of the painted surface. For this reason, paint industry spent a lot of money to protect their paints from microbial damage through the addition of antimicrobial agents (or preservatives) to paints. Two-coating formulations categories namely bactericides, fungicides and algaecides are used to control or inhibit the growth of bacteria and fungi and algae on the dry film of both water- and solvent borne paint respectively. A surface with waterborne paint represents a suitable environment for bacteria and fungi to grow, due to the availability of water and oxygen supply, suitable pH and

available nutrient sources. Raw materials heavily contaminated with spores of bacteria and fungi originated from dusty air, natural sources such as starches, pigments and minerals also participate greatly in the problem of paint contaminations with microbes. When microorganisms introduced into paint, they start to multiply and attack organic paint components leading to viscosity loss, followed by releasing enzymes capable of destroying cellulosic thickeners to smaller compounds that are no longer capable functioning as a thickener. In case of using cellulose as a thickener, it is degraded by cellulolytic enzymes producing cellobiose and then further degraded to glucose and other simple sugars which are finally fermented producing acids and carbon dioxide. The presence of CO_2 resulted to a stringy appearance and discolored of paints on the surface of material. Another postulation is that the enzyme was introduced into the system and there was no bacterial contamination of the paint. Aerobic microorganisms can be detected easily by using normal test methods for aerobic bacteria, which uses specific food media and is carried out in the presence of oxygen; however the anaerobic microorganisms cannot be detected easily because they are inhibited or killed in the presence of atmospheric oxygen. The following photographs are typical presentation of microbial analysis of a paint film. The addition of antimicrobial (or preservative) agent to paint resulted to the absence of bacterial, fungal and algal growth on the tested area of a paint film Fig. 3b, 4b and 5b indicating well protected paint film from microbial growth, however the paint film (on left) have shown microbial growth Figs. 3a, 4a and 5a.

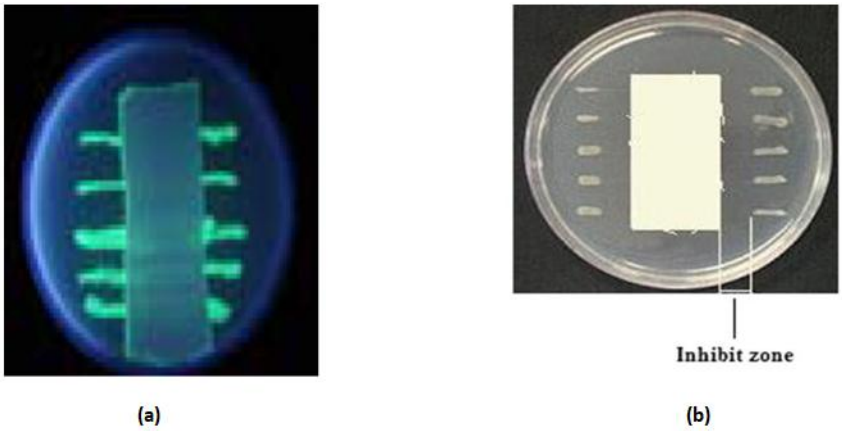


Fig. 3. Effect of anti-bacterial additives to paint: (a) unprotected paint film. (b) protected paint film

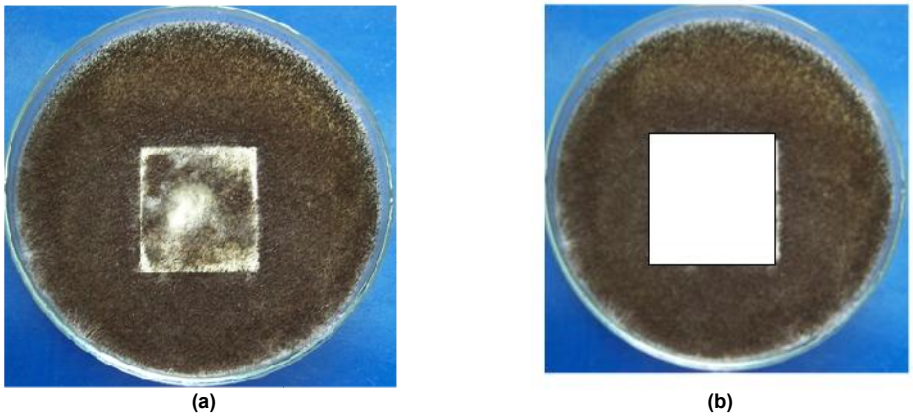
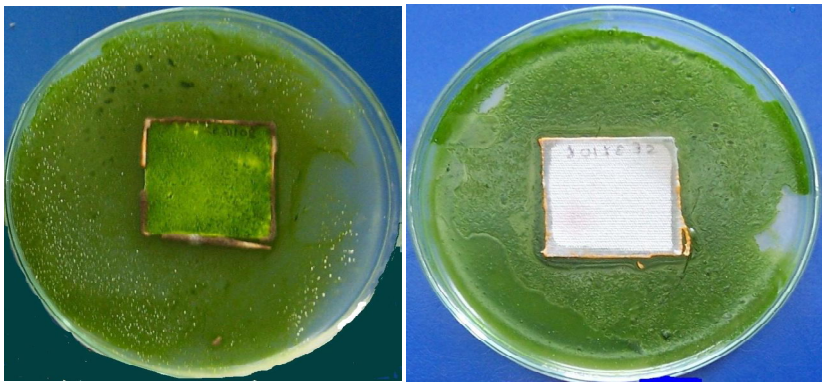


Fig. 4. Effect of antifungal additives to paint: (a) unprotected paint film. (b) protected paint film



(a) (b)

Fig. 5. Effect of anti-algal additives to paint: (a) unprotected paint film. (b) protected paint film

5. CONCLUSION

Antimicrobial agents are commonly included to paint formulations to preserve the product's integrity from microbial attack and to provide protection in the dry film against any bacterial, fungal and algal growth. Most paint consumers expect the aesthetic look of their painted surface to last for a long time. Microbial growth often effects paints and deteriorates paint structure. Antimicrobial agents for dry film protection play a large role in maintaining paint's physical beauty and keep any microbial growth away from the coated surface. The most common commercial dry film antimicrobial agents added to paints are zinc pyrithione (ZPT), carbendazim (CBZ), chlorothalonil (CTL) and others; however silver-based antimicrobial agents in its nano form such as silver nano particles (AgNPs) are another efficient widely known active for providing antimicrobial properties in many articles such as medical devices. Different postulations were suggested in the literature to elucidate the changes occur to bacterial cell components after silver nano-particles(AgNPs) treatment. The morphological changes occurred in the bacterial cell wall involve pits formation and leakage of cell contents leading to cell lysis. Pits formation leads to increase the membrane permeability and improper transport through the plasma membrane. This long-lasting situation may lead to the deterioration of homeostatic balance.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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