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Nanomaterials for Antimicrobial Coatings

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Abstract
The review article planned to explore the recent developments in nanomaterials for antimicrobial coatings. The application of nanotechnology is important to prevent the spreading of pandemic diseases and would be essential for the future and long-term success of biomedical devices. It has been proposed that graphene based nanosheets and some activated metallic nanoparticles can be used as long-lasting antiviral coatings to obstruct the spread of the current pandemic. These universal virucidal coatings can be applied for wide range of applications, not only against the coronavirus platforms but also against any other future viruses and microbial agents. In this article, we illustratively discussed the need of antimicrobial and antiviral surface coating and graphene-based nanomaterials as antimicrobial coating application.
Keywords: *Nanomaterials; Antimicrobial Coatings; Nanotechnology*

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I. Introduction

The COVID-19 pandemic has exaggerated the world's attention toward the spread of contamination facilitated by high touch surfaces. In response, surfaces and coatings capable of minimizing the presence of active viral pathogens are being explored for application in a variety of settings such as healthcare centers, long-term care facilities, public transport, schools, and various businesses to reduce human exposure and mitigate the spread of infectious pathogens. One area of particular significance in the transmission of infectious diseases is the ability of microbes to survive on surfaces, both in healthcare settings and on common surfaces. Considerable research has been conducted to investigate solutions that prevent bacterial transmission and biofilm formation by killing and/or reducing attachment of microbes. In order to highlight antimicrobial research which has definitively demonstrated antiviral capabilities, we will use the term antiviral to refer to nanomaterials and coatings which have proven antiviral capabilities, whereas the term antimicrobial will be used as a more general term to characterize nanomaterials and coatings that demonstrate effectiveness against other microorganisms, such as bacteria but to date have no proven antiviral capability, but in this study we present an inclusive study of metal and inorganic materials with a focus on nanomaterials with antiviral properties namely copper, silver, zinc, and titanium dioxide [1, 2].

II. Need of Antimicrobial and Antiviral Surface Coating

Biocontamination of medical devices and implants is a growing issue that causes medical complications and increased expenses. In the fight against biocontamination, developing synthetic surfaces, which reduce the adhesion of microbes and provide biocidal activity or combinatory effects, has emerged as a major global strategy. Advances in nanotechnology and biological sciences have made it possible to design smart surfaces for decreasing infections. Nevertheless, the clinical performance of these surfaces is highly depending on the choice of material. This study focuses on the antimicrobial surfaces with functional material coatings such as metal coating. The nanotechnology-based strategies presented here might be beneficial to produce materials that reduce or prevent the transmission of airborne viral droplets, once applied to biomedical devices and protective equipment of medical workers. The initial role of surface coatings in industrial applications was to provide protection from corrosion and mechanical resistance. Recently, with the advancement in nanoscience, polymer-/nanocomposite-based coatings have been developed and utilized for several purposes including biomedical applications, such as antibacterial surfaces there are many antimicrobial compounds, polymers/composites with confirmed anti-bacterial, anti-fungal or anti-viral activity that can be directly applied onto surfaces or incorporated into coatings to prevent the risk of spreading. Besides, combining basic and real-time sensing skills to the antimicrobial surfaces could aid in identifying the pathogens present in the environment and ultimately helping public health experts in controlling infectious disease pandemics [3-5].

III. Graphene-based Nanomaterials as Antimicrobial Surface Coatings

Graphene and its derivatives both show a wide range of antimicrobial activity including various types of viruses Among these materials, graphene oxide (GO), with the highest negative charge, show a higher affinity for positively charged viruses. It has been investigated that lipid bilayer of feline coronavirus can be adsorbed on GO and reduced GO (rGO) surfaces by electrostatic interactions and hydrogen bonding. Later on, this binding destroyed the viral membrane, thus confirming the GO efficacy against viruses. The negatively charged antiviral materials such as heparin, drugs, and heparan sulfate have also been used to modify the GO surface by conjugation, which resulted into the increased affinity of GO with positively charged residues of the viruses. Similarly, modified rGO with sulfate derivatives can wipe out herpes virus strains and orthopox virus. A study on GO suggests that the mRNA of the hepatitis C virus (HCV) to block the replication of HCV gene. Both GO, and rGO show antiviral properties due to their distinctive single-layer configuration, sharp edges and negatively charged surfaces, whereas, graphite (Gt) and graphite oxide (GtO), show negligible antiviral activity. So, it can be concluded that the presence of various surface functional groups, nanosheet structure and sharp edges all are important features to exhibit antiviral properties. Few-layer graphene in face masks coating due to its superhydrophobic properties, which inhibit the adhering of virus-containing aerosols. However, it needs laser treatment and sunlight to make it reusable. Other researchers have explored the use of graphene based nanomaterials in nano-vaccines as drug delivery agents, biosensors for diagnostic purposes and antiviral nanocomposites. Graphene based materials plays key role in the current pandemic, including graphene-based composites for 3D printing masks and as surface coating materials. Some authors have proposed few mechanisms to demonstrate the extraordinary antimicrobial properties of graphene based nanosheets.

This perspective mainly focuses on the use of graphene based nanosheets for antiviral surface coatings at high-risk areas in hospitals, schools, and public places where the risk of spread is very high. After reviewing the previously proposed mechanisms for antibacterial properties of graphene based nanosheets, a novel surface coating has been proposed in the current perspective using graphene based nanosheets, metallic nanoparticles and some reported non-ionic polymeric materials. The synergistic antimicrobial effect of these materials can be applied to develop robust antiviral coatings that can be applied in a spray or paint on many surfaces. Developing surface protective coatings with excellent antiviral properties for diverse surfaces can help to break the chain of COVID-19. Graphene-based surface coatings with proven antimicrobial metals can play a vital role to inactivate or reduce the survival time of SARS-CoV-2 on many surfaces. Some reported composites include single-layer graphene (SLG)/multilayer graphene (MLG)-copper composite, SLG/MLG-silver composite, GO-copper composite, GO-silver composite and many other combinations. High-performance coatings can be developed by varying the concentration of metal nanoparticles to effectively destabilize and minimize the survival time of SARS-CoV-2 on high contact surfaces, i.e., medical and surgical equipment, PPEs and hospital door handles, etc. It has been proposed that new flexible and reusable GO incorporated cotton fabrics can be designed as a new antimicrobial material for many medical-related applications. Similarly, for antiviral drugs and vaccines, nano-vaccines can be developed where graphene material act as inactive Virus-Like Particles (VLPs). Multifunctional antimicrobial graphene based nanosheets can prove as ideal products for environmental pollution protection, wastewater treatment, food safety and any other application where control of bacteria, fungi, and viruses is required. So, it is the pressing need of time to identify the long-term and short-term approaches that can be fully employed to cope with the current and any future unforeseen outbreak [6-8].

IV. Need of Antimicrobial Coatings in Water Industry

Microorganisms present in aqueous environments can attach onto surfaces that can lead to biofilm formation and eventually biofouling. Planktonic microbial cells, once attached onto an abiotic or biotic surface, multiply until a mature biofilm is formed Biofilms influence the chemistry of interfacial and liquid phases and surfaces, which have serious negative impacts in industry. (i)Heat transfer in heat-exchange units is reduced, (ii) water systems are contaminated (iii) corrosion of metal structures is facilitated (iv) In cooling water towers, for example, half of the equipment defects are due to biofouling, resulting in corrosion leading to downtime, decreased energy efficiency, clogging and increased heat transfer resistance. Failures of power stations in the United States are estimated at 4% and Europe spends about 10 billion Euro per year on heat exchanger fouling. The design of self-cleaning and antimicrobial surfaces is a very attractive alternative to prohibit biofouling. Antimicrobial and antifouling coatings have been developed to manufacture surfaces that prevent biological contamination and extend the lifespan of equipment prone to biofouling and biocorrosion. Dependent on the application of the material, the requirements of self-clean coatings include,

(i) Antimicrobial efficiency for relevant microbes in the specific environment;
(ii) Longevity;
(iii) Compatibility with the properties of the material and
(iv) Minimum to zero toxicity to the environment.

In this respect, the use of nanotechnology in the design and fabrication of antimicrobial and antifouling coatings have yielded promising results. Nanoparticles are not only optimally utilized in coatings, but fewer nanoparticles are needed for fabrication of these coatings therefore reducing manufacturing costs. One of the major problems in the water treatment industry is biofouling. The high cost and labor involved in controlling and cleaning biofilm formation and repairing and replacing equipment due to corrosion is a concern. Lately, research has focused on applying nanotechnology in antimicrobial coatings and films as alternative methods to prohibit biofouling. The research discussed demonstrated that antimicrobial coatings and films could be a promising preventative application for biofouling in water treatment systems. The question remains as to which technique would be the most applicable in the particular industry. Factors that will influence this decision include the type of surface material; size of area that needs to be coated; location of the surface; water quality, e.g., pH, bacterial and chemical contaminants; cost effectiveness in terms of material and equipment needed and technical expertise available. The environmental impact of released nanoparticles is also a concern and should be addressed in future studies by focusing on environmentally friendly coatings and biocides. The ideal coating or film for the water industry would be a safe and permanent antimicrobial coating with a long lifetime which is easily scalable and is cost effective [9].

V. Conclusions

New nanomaterials can be explored for the development of multipurpose efficient disinfection systems that can be applied on permanent basis having self-reactivation mechanisms. Multifunctional antimicrobial graphene nanosheets can prove as ideal products for environmental pollution protection, wastewater treatment, food safety and any other application where control of bacteria, fungi, and viruses is required. So, it is the pressing need of time to identify the long-term and short-term approaches that can be fully employed to cope with the current and any future unexpected outbreak.

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