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Review Article

## Antimicrobial Paper Embedded with Nanoparticles as Spread-Breaker for Corona Virus -

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## ABSTRACT

For combatting the submicroscopic bacteria and viruses, antimicrobial paper incorporated with nano particles, can be very effective. It is exigent at the present juncture to use such antimicrobial papers and products to arrest spread and kill the deadly corona virus.

Differences between SARS-CoV1 and SARS-CoV-2 are explained along with the survival period of CoV-2 on different surfaces. The developments taken place in antibacterial paper and antibacterial tissue paper to combat the hospital-induced diseases including Methicillin-resistant *Staphylococcus aureus*(MRSA) bacteria (or super bugs) prior to the corona virus epidemics, have been specified. However, paper industries engaged in these developments, have taken this epidemic as opportunity for plunging into manufacturing antimicrobial paper, having ability to act as spread-breaker and kill the corona virus.

The different antibacterial nanoparticles available and procedure for their embedment in the existing mineral pigments and a new concept of exchanging these metallic ions inside clay minerals, such as vermiculite and montmorillonite, has been introduced. Though production of antibacterial paper is going on for the last ten years and production of antimicrobial paper has started, the manufacturing processes are not disclosed.

The recent developments taken place (in the last 3 months) in antimicrobial additive and industrial production of antimicrobial paper in different parts of the world to combat corona virus, have been brought out along with their test results in killing corona virus. The mechanism of silver ion technology in curbing the growth and killing of corona virus, is explained [1]. The commercial aspect attributing to the growth of the antimicrobial papers, is also briefed here. It is expected that the technical information, provided in this paper will help increasing production of antimicrobial paper in the world and to arrest the spread of corona virus.

## INTRODUCTION

We are witnessing the horror of Corona virus epidemics since the beginning of this year, causing deaths of more than a million and infections to several millions of people in the world. Governments, hospital, testing laboratory and security staff members, doctors and scientists all are playing their roles to arrest infections due to this epidemic. Some industries are also working hard to meet the rapid production and supply of testing and personal protective equipment to combat the spread of epidemics. In this challenging time, we are all looking to do everything we can, to reduce the spread of infection to protect ourselves and others and broadening availability of antibacterial papers to all sectors.

Writing and printing, packaging, tissue and even newsprint sectors of the paper industry, have roles to play at the present juncture as all these papers are used by the society in everyday life; in schools, colleges, offices, hospitals, transport, travel, restaurants; grocery and other goods packaging, face and nose wiping tissue papers and newspapers. The corona virus may get contaminated on these papers and spread infection to others. Therefore, all eyes are now on the paper industry to supply paper, packaging and tissue papers, having antibacterial properties so that the bacteria and virus, when they come in contact with the antibacterial paper, are killed and are unable to spread.

Paper is such a common commodity and used in such large quantity that developing manufacturing facilities for thousands of tonnes of antibacterial paper per day, can be really a herculean task. However, in view of this deadly disease, the paper industry will have to pull up their socks to prepare itself in a more challenging way. On the other hand, the industries, who will be able to show result on antibacterial properties, will benefit more than ever before and will create history.

## SARS-COV1, SARS-COV-2 AND SURFACES

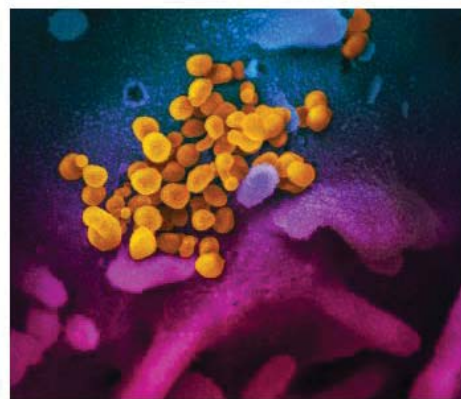
Before delving into the depth of antibacterial paper and products, serving as spread-arrester, it may be worthwhile understanding the difference between SARS-CoV1 and SARS-CoV2 in terms of their survival rate on different surfaces [2-4] and contamination fear.

The SEM (Scanning electron microscopy) and TEM (Transmission electron microscopy) of the SARS-CoV-2 (also known as 2019-nCoV), that causes COVID-19 are presented in figure 1 and figure 2 respectively. As these microscopes have very high resolutions, the sub microscopic viruses could be seen and photographed.

The virus that causes coronavirus disease 2019 (COVID-19) is stable for several hours to days in aerosols and on surfaces [2], according to the study. The scientists [2] have experimented that SARS-CoV-2 survive for different periods on different objects:

- in aerosols for up to 3 hours,
- up to 4 hours on copper,
- up to 24 hours on cardboard and
- up to two to three days on plastic and stainless steel.

It means that if an infected person touches the plastic or stainless steel today, there is fear that the infection can be transferred to a person who touches it in 2 to 3 days. If the surface is cardboard,



**Figure 1:** Scanning electron microscope image (2) showing SARS-CoV-2 (yellow), also known as 2019-nCoV, the virus that causes COVID-19, isolated from a patient in the U.S., emerging from the surface of cells (blue/pink) cultured in the laboratory (NIAID).

the fear of infection will be normally limited to 24 hours and if it is copper, it will continue for 4 hours. Copper has antibacterial property, while stainless steel lacks in this property. Cardboard may behave differently if it is wet, where microbes can reside for a longer period than when it is dry.

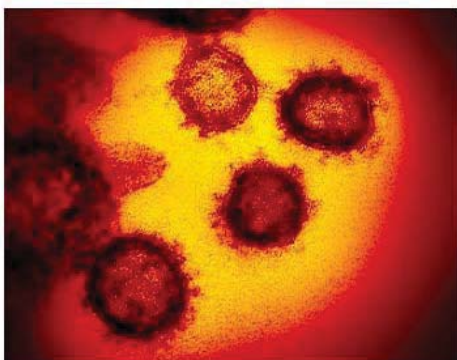
Because of the inherent surface property, the stainless steel surface becomes vulnerable to infection for such a long period, while in copper, the virus cannot survive for more than four hours. Copper and its alloys such as brass and bronze are known to have antibacterial property and this value of copper is recognized thousands of years before. Stainless steel, although looks to be clean, it does not have antibacterial property like that of copper. Therefore, researchers are developing antibacterial coating material, to coat the stainless steel for use in healthcare centres. Plastics do not have any antibacterial property and therefore, the virus lives there up to 2 to 3 days. Ordinary plastics do not have any antibacterial property and therefore, developments of bioplastics and antibacterial plastics are going on. The normal plastics and stainless steel used in the healthcare centres therefore could be surfaces conducive for the virus to proliferate.

The information generated by NIAID on the virus surviving for different periods on different surfaces, is quite valuable, based on which people are cautioned not to touch any object. The droplets of virus from the infected persons (aerosols) remain in the air for 3-4 hours and therefore, social distancing for more than 2 metres and using a mask is suggested. In fact, these are the two major precautionary measures, being rigorously followed by many countries and there has been spectacular results of reduced infection rate and death cases in the last one or two months.

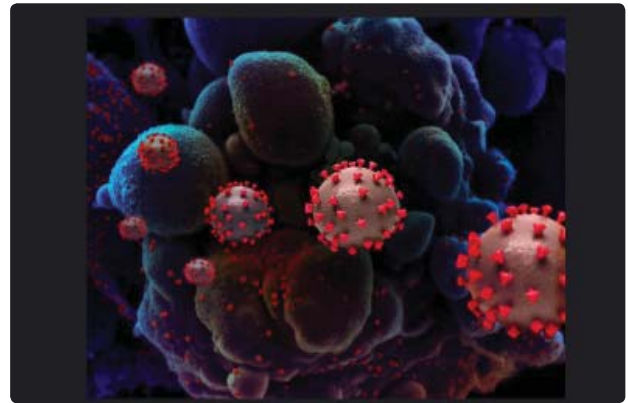
Figure 3 presents the latest image from NIAID on SARS-CoV-2, which causes COVID-19.

The NIH scientists [3] compared how the environment affects SARS-CoV-2 and SARS-CoV-1, which cause SARS. SARS-CoV-1, like its successor now is circulating across the globe, emerged from China and infected more than 8,000 people in 2002 and 2003. The success in eradication of SARS-CoV-1 is attributed to firstly intensive contact tracing and secondly to case isolation measures. The reasons may appear simple but they were very effective in eradication of a deadly virus, because of which no cases have been found after 2004.

SARS-CoV-1 and SARS-CoV-2 have many similarities but there are differences resulting from their genomes. There are significant



**Figure 2:** Transmission electron microscope (TEM) image showing SARS-CoV-2, the virus that causes COVID-19, isolated from a patient in the U.S., emerging from the surface of cells cultured in the laboratory (NIAID).



**Figure 3:** SEM Image of novel corona virus SARS-CoV-2 (Courtesy-NIAID).

differences the way these are transmitted from person to person and symptoms. In the tests conducted [3] on the survival duration of these two types of virus, no major differences were observed but in reality, COVID-19 has become much more deadly and spreading ability than the CoV-1. The reasons are not thoroughly understood but it is likely that there may be differences in their structures and genome characteristics.

The NIH study had probably the objective of studying the survival rate of the virus, emitted from the infected person on common surfaces while touching or coughing, which are used in the house and hospitals; namely metals, cardboard and plastics. These three materials encompass large number of items, the cardboard for example, cover all the wood fibre-containing papers and wooden boxes used in delivering food items at home; the two metals, copper and stainless steel representing the cooking utensils at home and construction materials in the factories and other areas; while plastics are used in form of bags and packaging for a large number of drinking and eating items. These materials are of common use during the present epidemics.

The scientists considered worthwhile determining the different periods for survival of the virus on these surfaces so that people are advised not to touch these objects till certain periods. For example, the cardboard boxes used for delivering food and groceries, should not be touched in hand and should not be mingled inside the kitchen with other items; it is advisable to use gloves and keep it outside for more than 24 hours.

The scientists [3] highlighted additional observations from their study:

- One of the observations was the viability of SARS-CoV-1 and SARS-CoV-2 on these surfaces, which did not differ much but then it is not comprehensible how the later has become more deadly than the 1<sup>st</sup>one. The exact interpretation of this observation may be traced from their structural and topographical features, which are distinctly different.
- As SARS-CoV-1 had the symptom of cold at the early stage unlike the present Corona virus, the infected person was having some hint on the infection, while on infection of the present virus, no recognizable symptom is felt by the person infected and he becomes a new source of spreading the virus. If the infected person can have some symptom or feeling, he can certainly separate himself at home in particular but this



is not the case unfortunately. Therefore, on entering home, everyone is advised to carry out some activities like drinking hot water or inhale hot water vapour so that if there is any initiation of infection by the virus, which is normally in the throat, will get eliminated through the stomach. This will not give time for proliferation of the virus in the respiratory system. Corona virus needs a living host for proliferation and it cannot proliferate on its own.

- The fact that the infected person, does not feel the immediate effect of infection due to the present corona virus unlike the CoV-1, has serious repercussions on the precautionary measures to be taken and on the medication. In the 1<sup>st</sup> Covid, the infected person was able to know early and thus the doctor could prescribe some antibiotics or other medicine immediately. This was also enabling the infected person to remain away from the other family members to avoid infection.
- It is well-understood now that SARS-CoV-2 appear to be spreading more easily in the community rather than in the hospitals. In the hospitals, all precautionary measures can be taken, but very little in the community and other meeting places like shopping stores, offices, bars, trains, buses or in schools etc. This has led to lock-down measures with total closure of these places. This was not the case with the earlier virus, SARS-CoV-1.
- It cannot, however, be said that the spreading of present corona virus, cannot occur inside the healthcare centres because the aerosols of infected persons falling on surfaces of different objects, existing inside the hospitals, can cause spreading.

The findings of the scientists that SARS-CoV-2, the virus that causes COVID-19, can be detected in aerosols for up to three hours and on plastic and stainless steel surfaces for up to three days [4], emphasize the importance of hand washing and disinfecting frequently touched surfaces to protect against infection.

The spreading of present corona virus is thus not only with the human factor but also through different objects as discussed above. Ultimately howsoever, people are kept disinfected, because of presence of the virus on the external objects, total eradication of this epidemic will take time. Time is definitely one factor but all these objects, specially used by the community need to be cleaned and disinfected. However, the infections on the sea beach or in a big park, for example, cannot be disinfected and social distancing is the only way.

How much careful one may be but contact with the virus responsible for the current outbreak, SARS-CoV-2, may be simply by touching a surface or object infected by the virus and then touch the face or ear.

More than the touching of surfaces, it is through the droplets while coughing or sneezing by an infected person that the virus gets transmitted. The droplets remain in the atmosphere even after the infected person passes away from the place. Therefore, it is advisable to use mask in the public places, even if no one is seen at sight. In bars and other gathering places, the spreading through droplets, may be common.

The study on the survival rate of the virus on different surfaces and

in the atmosphere, has been studied by a group of scientists following to rigorous testing procedure on the virus for different durations after injection of the virus on the surfaces. The group was led by Vincent Munster of NIH's National Institute of Allergy and Infectious Diseases (NIAID). One way of carrying out the test is collecting virus sample from the surface at regular intervals till zero presence of the virus on the surface. The samples are collected following to standard procedures and then subjected to testing procedures.

They mimicked how viruses are spread by an infected person onto everyday surfaces in a household or hospital setting, through coughing or touching objects. The project can have two-fold objectives, firstly to study the nature of surface and secondly the duration of survival of the virus on these surfaces, the results may be extrapolated to similar infection on the materials at home and in hospital.

They compared the results to that of the closely related SARS-CoV-1, which was responsible for the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2002-2004 [2].

The reason for selecting the four objects of plastic, stainless steel, copper and cardboard by the scientists, was to study the behaviours of the virus on multiple types of materials available at home and outside. The procedure to test the virus in aerosol, was made in a rotating drum, where the droplets can be kept in suspended form as in the atmosphere.

It is to be noted that the time of survival of the virus on the different surfaces, is based on the conditions, followed by the scientists of NIAID. The results may vary if the conditions for testing and sample preparation are changed. For example, the aerosol sample if not kept in suspended state in a rotating drum, the test results may vary. Similarly, the other samples of cardboard or the stainless and plastics with different compositions and surface characteristics, will cause variation in the test result.

The fact that infection lasts up to 24 hours on the cardboard and four hours on the copper metal, is based on the experimental conditions maintained in the tests at NIH.

One of the most important discovery by these scientists is that the present corona virus can linger on the aerosols up to three hours.

Like all other testing of materials, the survival period mentioned above are strictly based on the laboratory conditions, which can vary if the humidity, temperature, passage of air and the concentration of the virus on the surfaces, are changed. This is well-known in all testing and therefore there are definite conditioning procedures followed everywhere.

These findings show that SARS-CoV-2 is actually quite similar to SARS-CoV-1 in terms of stability in the environment.

The reason for discussing here on the SARS, which gained importance in 2002-2004, with the present Corona virus, is to derive procedure for curbing or eradication of infection of the present corona virus from the experiences of the earlier virus. This is specially considered indispensable in absence of practically total lack of knowledge on the present corona virus, which has erupted all on a sudden, giving no time to the world to prepare to fight against it.

On the other hand, it indicates that the major differences in the epidemiology of these viruses probably arise from other factors, especially the ability of SARS-CoV-2 to be transmitted by people not exhibiting clear symptoms [5].



The research on all the topics covered above will continue and will become theme of the future research projects. Once the reason is clearly understood, probably some curing method may easily be derived. One may remain optimist that the present and future researches will show ways for fighting corona virus appropriately and can cease death of people.

## DEFINITIONS AND CONCEPTS

### Definitions (6)

#### Antibacterial

A product that kills or inhibits the growth of bacteria, generally in food, on inanimate surfaces or on hands.

#### Difference between antimicrobial and antibacterial

An antimicrobial inhibits the growth of, or acts to destroy harmful microorganisms such as bacteria, fungi and moulds. An antibacterial prevents the growth of bacteria specifically.

#### Bacteria

Single-celled micro-organisms that can affect humans, plants and animals; some bacteria cause disease, some are beneficial.

#### Virus

A term for a group of microbes that are incapable of reproducing on their own, and must invade a host cell in order to use its genetic machinery for reproduction. Viruses are smaller than bacteria, and are responsible for the most common human diseases, the common cold and influenza. Viruses are also responsible for more serious diseases such as AIDS, hepatitis B and hepatitis C and recent corona virus epidemics.

#### MRSA

Methicillin Resistant Staphylococcus Aureus (MRSA): Aerobic Gram positive coccus. Part of the normal flora of the skin, intestinal and genital tracts and mucous membranes of warm blooded animals. An opportunistic pathogen causing a wide variety of infections. There are currently 27 known pathogenic serotypes of MRSA, each highly contagious and resistant to most antibiotic treatments. Common in hospital acquired infections.

#### SARS (Severe Acute Respiratory Syndrome)

The present corona virus is SARS-CoV-2 (also known as 2019-nCoV) that causes COVID-19. SARS-CoV-1 occurred in 2002-2003 and now completely eradicated.

#### Nanoparticles

Particles in the range of 1-100 nm.

The term bacteria was devised in the 19<sup>th</sup> century by the German botanist Ferdinand Cohn, and it is based on the Greek word “bakterion” meaning a small rod. Bacteria are single-celled micro-organisms devoid of chlorophyll, and they multiply by simple division, having round, rod-like, spiral or lamentous single-celled or non-cellular bodies often gathered into colonies [6].

Some bacteria may cause illness such as strep throat, ear infections, pneumonia, tuberculosis, etc. Methicillin-resistant *Staphylococcus aureus* (MRSA) bacteria (or super bugs) are the bacteria which are also of concern [6,7]. The excessive use of antibacterial household

cleaners is said to help super bugs survive. If bacteria are exposed to repeated doses of antibiotics, they will genetically mutate, resulting in super bugs.

Antimicrobial agents are chemicals used to kill or inhibit the growth of micro-organisms whether they are bacteria, viruses or fungi [8]. They can be bactericidal, killing the organism concerned, or bacteriostatic, inhibiting the growth of the organisms concerned thereby giving the immunity system of the host time to act.

Bacteria and virus are in the micron and submicron sizes and in order to react effectively with these micro-organisms, harbouring help of nanotechnology, which deals in particle sizes of even smaller than these micro-organisms, can serve the objective effectively. Moreover, because of the high surface area and antibacterial properties, the nano particles can act as killers for the viruses and the bacteria [8] as shown in figure 4.

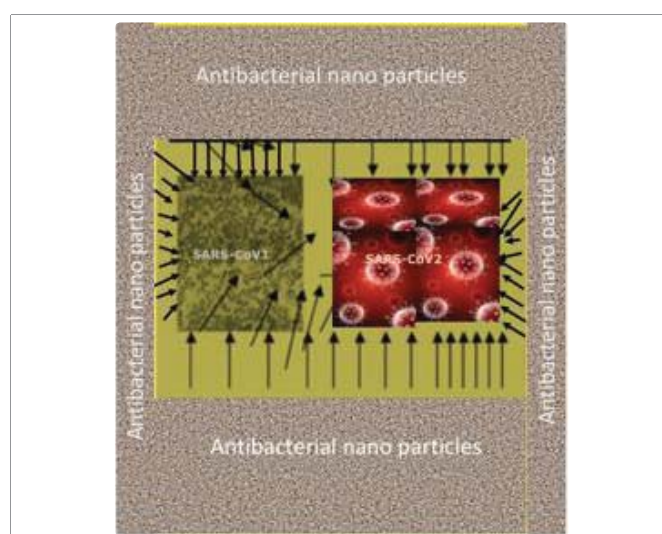


Figure 4: Schema demonstrating killing of bacteria and viruses with antibacterial paper (8).

## ANTIMICROBIAL PAPER

Like all other industries and organisations in the world, the pulp and paper industries also never anticipated that corona virus can become a world calamity, keeping all activities standstill and cause deaths of millions of people. While efforts for developing antibacterial paper for reducing the hospital induced diseases and MRSA etc, were being made by the paper industry for the last few years (6), suddenly a new challenge appeared and all focus are now on inventing new paper products to serve arresting the spread of corona virus.

Based on the duration of antimicrobial effect and type of antimicrobial agent used in production of paper, it may be classified into two categories:

- A) Antimicrobial paper with long lasting antimicrobial property and
- B) Antimicrobial paper with short duration of antimicrobial property.

In the 2<sup>nd</sup> category, mostly antibacterial tissue papers, available in the market now may be included, while in the 1<sup>st</sup> category, writing and printing type of papers used in the hospitals for patient’s file and

prescriptions etc, office papers, packaging paper, menu card in the restaurants, papers for school books and stationery are the products.

Material wise, in the 2<sup>nd</sup> category, mostly organic compounds are used, while in the 1<sup>st</sup> one nano materials like silver and other inorganic compounds are added in aqueous solutions or with solvents as antibacterial additive. Obviously, for combatting corona virus from spreading, the 1<sup>st</sup> category is much needed, while the 2<sup>nd</sup> category may be used for common uses, notably as hand, face and nose wipes.

Figure 5 presents the two types of antibacterial paper.

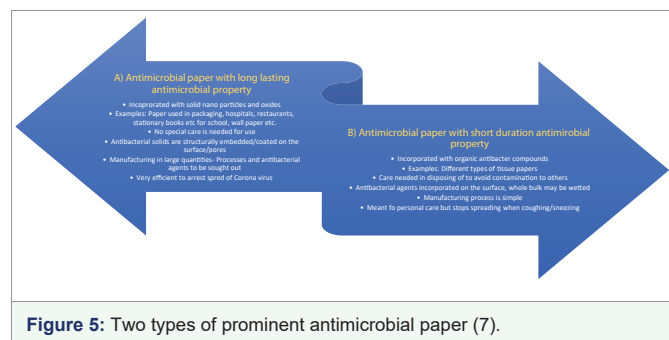


Figure 5: Two types of prominent antimicrobial paper (7).

### Nanotechnology-based antimicrobial paper and other products

The recent developments on Antimicrobial paper are mostly (A) types of papers, based on incorporation of nano particles having antimicrobial properties [8]. The paper could be packaging paper, tissue paper, wall paper and writing and printing papers used in the hospital for the prescriptions, files etc. The efficacy of Ag-nano particles as antibacterial agent, is well-known and many products based on Ag-nano particles have been produced including additive for antibacterial paper [6,9-13].

In order to arrest the spread of corona virus, people are advised to stay at home and it does help in curbing the spread of corona virus to some extent. However, it is necessary to use proper mask, gloves and sanitizers etc as a measure to avoid infection of the virus. Various nanotechnology products are available [14] to equip people for combating COVID-19.

Lot of developments have taken place to enhance the quality of masks and gloves, using nano particles and nanofibres to stop corona virus to enter into our respiratory system. However, quality antibacterial liquid detergents, sanitizers, shampoos and disinfectants can also be used.

It has been found that the microbes in the hand are eliminated to different percentages depending upon the quality of antibacterial and antiviral products; lesser the microbes in the hand, better is the antibacterial property of the liquid washing products. Sometime, adulterated products are even available in the market and one has to be quite careful; better to buy branded and quality antibacterial products. The need has arisen more today because of the corona virus epidemics.

Graphene, nanodiamond, polymer nanofibres (e.g., polyacrylonitrile), and such nanoparticles as silver, titanium dioxide, and copper oxide are commonly incorporated into these categories of products so as to contribute to their proficiency.

The overwhelming demand for nano-enabled or -enhanced gowns, aprons, scrubs, and protective gear has set off a race among health centres. In order to curb access of virus into our homes, efficient air-filtration systems, called as HEPA (High Efficiency Particulate Air), are now available in the market, which can capture not only the particulate matter but also bacteria, mold spores and viruses. It is important for preventing the hospital-induced micro-organisms.

Some of the HEPA products, when activated by Ultraviolet (UV) light, have the ability to filter particles and microbes as low as 3nm, though the majority of bacteria and virus are much above this dimension. The UV region covers wavelength range of 100 to 400 nm.

The first-ever molecular photo catalyst air purifier works based on a chemical reaction between the nanoparticles and the pollutants under the presence of UV light. There have been spectacular developments in the filtering system and the latest electric filtering system, where electric shock is employed, filtration of particles < 0.3 nm is possible, where it can be assured zero-risk for virus access into the system. These ventilation system does not contain filters that can get clogged, therefore the purification efficiency stays high at all times [13].

It is felt that nanotechnology is underutilised in a time of crisis like now [15]. It is exigent to review the various research studies undertaken for contributions, likely to be made by nanotechnology not only to stop spreading of the virus but also in diagnostics and treatment.

Table 1 gives below some of the developments, taking place recently on antibacterial paper and related products at industrial scale. The details of these developments are discussed below.

**Reducing feline corona virus on paper surface:** Addmaster in UK is now the major [16] producer and supplier of antibacterial additives for paper as well as textiles, paint and coatings. It is engaged in developing antibacterial additives and testing MRSA in hospitals and other healthcare settings. It has gained lot of experience and expertise on antiviral products and now tackling the Corona virus crisis. Numerous testing on coronaviruses have been made by this Company, particularly the feline strain as it is similar to Covid-19. To date, commercial labs cannot handle Covid-19, so all testing is against feline coronavirus. However, the scientific consensus is that it will be deactivated in the same way.

The Company feels that to date, the antiviral results have been very encouraging. Porous surfaces such as textiles and paper are showing a reduction of > 95% of these virus in 2 hours and products are already being used. Solid surfaces were always thought of not possessing antiviral properties but with formulation enhancements and the particular lipid coatings in the coronavirus family, there are visibly positive results of > 80% (for the most difficult polymers) in 2 hours. Tests are continuing with other polymers and coatings and results are expected in the range of 95% in 2 hours. These properties are all designed to last for the life of the product, rather than the temporary action of a disinfectant, therefore enhancing hygiene protocols.

**Biomaster antimicrobial additives:** In manufacturing of antibacterial paper in a paper mill, three things are to be kept in mind;

- (i) the effectiveness of the antibacterial property in the whole paper surface is to be maintained and
- (ii) quality of paper such as surface, optical and strength properties etc should not deteriorate.



Table 1: Recent developments in antibacterial paper and related products in the post corona virus period.

Application	Organization	Key technology	Result & Impact on the future	Reference
Reducing Feline Corona virus on paper surface	Add master, UK	Developer and producer of antibacterial additives for paper. Testing now on the antibacterial effect of Corona virus on paper surfaces. Its products are already added to paper in industry and production going on.	Porous surfaces of paper showing reduction of virus >95% in 2 hours. Promising for immediate use by the paper industry.	[15]
Antimicrobial print services	Galloways, UK	Performs printing on Biomaster protected paper and board providing effective, lasting antimicrobial protection. It assures risk of contamination from outside and at the same time, prevents proliferation and accumulation of bacteria in the storage area.	In food service industry this specialist paper is used for order books and menu cards, in education used for books and stationery, in hospital, patient's papers; in work places, protecting cover spaces; in travel, in-flight safety cards	[16]
Manufacturing antimicrobial paper	James Cropper, UK	James Cropper papers claim to be effective against Feline Coronavirus with this antibacterial technology. While PaperGard has been regularly used for the production of medical and healthcare documents, this technology can be applied across the portfolio of paper products manufactured by James Cropper.	Papers and boards for premium packaging or greetings cards that are subject to a lot of handling.	[17]
New antimicrobial paper line	American Eagle Paper Mills, USA	It has introduced a new antimicrobial paper line. The paper products have been treated with Biomaster silver ion technology to offer antimicrobial protection for the lifetime of the paper.	Paper suitable for use in restaurant and food service facilities	[18]
Antimicrobial face mask	Urofoam, UK	UK polyurethane engineers Urofoam has developed a unique face mask containing Biomaster technology which can be worn to shield the wearer and those around them against disease-carrying droplets. Dropstop is washable and pricewise it is quite affordable.	Public transport users, office staff, care workers, retail staff, transport and delivery workers	[19]
Antimicrobial tissue paper using nanocellulose	NC State's College of Natural Resources, USA	Researchers have developed an antimicrobial tissue paper, which can prevent the spread of COVID-19 and other infectious diseases. It is based on hydrophobic spray-coating of chitosan and cellulose nanocrystals composite.	Tissue paper for future use	[20]
Disposable tissue paper towel	Sofidel, Italy	Sofidel has launched new Nicky Defend, a disposable tissue paper towel with antibacterial lotion designed for the Consumer market and specifically developed to guarantee proper hygiene.	Tissue paper not ensured for corona virus	[21]
Antibacterial tissue paper	Kimberly Clarke	Kimberly-Clark made the 1 <sup>st</sup> patent of antibacterial tissue paper, where the anti-viral components needed to be placed in a middle layer of the three-ply tissue because they could be irritating if they came in contact with the skin. The tissues reached the market in 2003. The Company has been trying to upgrade the quality continuously and in 2009, the antibacterial property was further enhanced so as to combat the Swine flu (H1N1 influenza), which was considered quite life-threatening for some time.	Can protect spread of virus while coughing/sneezing	

(iii) Another important aspect is the cost; which should not be too high and should be within the affordable range of the customer.

The Biomaster additive can be added in two locations:

- a) During manufacture of uncoated paper and
- b) In the size press.

The additive can be applied to both coated paper and board such as photocopying paper, file folders and packaging paper for food and groceries etc. and carbonless paper to provide effective and lasting antimicrobial paper protection. Carbonless paper is the specialty paper; on writing at the top paper, the writing is reproduced on the lower paper; i.e. without the use of carbon paper of earlier time. It is specially used in the airport as air-ticket and in the banks.

Preparing food hygienically can be a crucial way of reducing the risk of catching an unpleasant food poisoning illness as bacteria can be transferred easily around the kitchen from chopping boards, utensils and even contaminated packaging.

The paper used in the food packing and baking in the kitchen

and take-away, is also produced with antibacterial property. These include the cling film, baking foil and parchment paper; which are produced from kraft brown paper or packaging paper with antimicrobial additive. According to the website of this Company, leading supermarket chain Asda now uses the Biomaster protected dispenser in their product lines.

Biomaster can be added at any stage of the manufacturing process and is available in master batch, liquid or powder formulations for plastics, textiles, paper and coatings. The antimicrobial additive like silver ion binds with the virus, firmly as a result of which, it fails to grow and proliferate, neither it can produce energy and ultimately it dies. The nanoparticle based antimicrobial agent remains adhered to the surface of paper as long as it is not destroyed by putting in water and boiling or any harsh treatment and if it is properly preserved, it can last long.

**Biomaster antibacterial technology:** It is claimed by Galloways that Biomaster protected paper and board provides effective, lasting antimicrobial protection [17]. The fear of infection from person to person and proliferation of bacteria in the storage area, is reduced to a great extent with this use. When bacteria come into contact with a



Biomaster protected surface, the silver-ion technology prevents them from growing, producing energy or replicating, basically meaning- the bacteria die. It has multiple uses:

- One of the mass scale use of antibacterial paper is conceived in the food sector. The food can be preserved for longer period if it is incorporated with antibacterial additive. In view of the food scarcity in the world, it can be a boon to the society for the future.
- Each restaurant has normally a menu card, which is touched by every customer and if it is infected, then spreading of virus cannot be stopped. Similarly, in hotel rooms, often books are kept and anybody staying in the room will touch it. Therefore, books and menu cards in the restaurants and hotels need to be protected from infection using antimicrobial paper.
- In education, it is used for books and stationery,
- In the travel and leisure sector, it is used for in-flight safety cards and
- Obviously in health care, it is essential to do everything to ensure patient safety; so it is being used for patient files help combat the spread of potential infections. Paper is a potential source of cross-contamination in the hospitals. Anything from patient files and folders to food packaging and wall coverings are possible transmission points for harmful microbes.
- A company is looking to protect the workstations with protective paper coverings of this antibacterial paper so that staff can work safely.

**Antimicrobial paper manufacturing by James Cropper Paper mill:** Figure 6 presents the science behind the silver ion based antibacterial paper, manufactured by the paper mill, James Cropper paper mill in UK.

Unlike antibiotics, micro-organisms are unable to build up a resistance to the way in which silver ions disrupt their growth.

- Silver ions bind to the cell wall of the micro-organism; preventing growth.
- The silver ions have antibacterial property and in presence of these ions, the enzyme production cannot take place normally and ultimately it cannot produce energy.
- Formation of DNA cannot take place on the antimicrobial paper because of the silver ions there and thus no new cells can proliferate.
- This process does not allow the microorganisms to develop any resistance.

The antimicrobial paper produced by the James Cropper paper mill in UK (Figure 7), is treated with the antimicrobial additive from Biomaster, which contains the silver ions and thus it can prevent proliferation of bacteria and even the Feline Coronavirus, as claimed by the paper mill.

The paper has two sides, one is on the paper machine side and the other on the other side and in the manufacturing of antimicrobial paper, both the sides are treated with the silver ions additive. PaperGard harnesses its expertise and now gives reassurance to customers in a wide range of applications, from premium boxes for

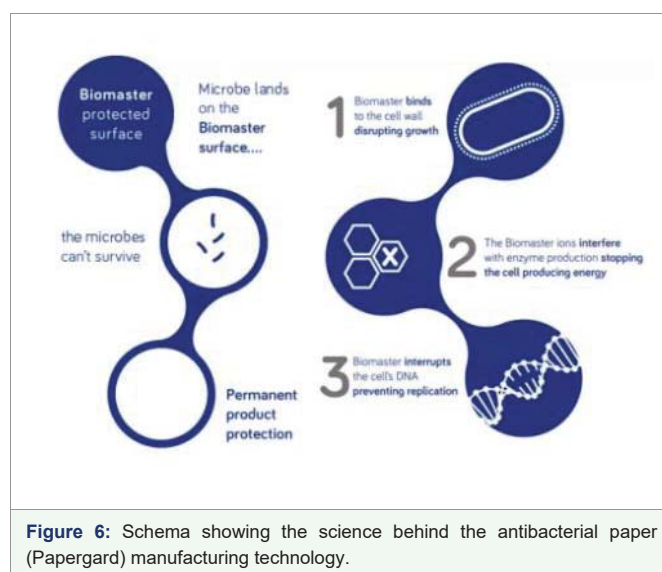


Figure 6: Schema showing the science behind the antibacterial paper (Papergard) manufacturing technology.



Figure 7: Paper rolls with antimicrobial property to kill corona virus.

luxury brands to greetings cards and envelopes.

The Company [18] has announced that its PaperGard range with antimicrobial technology, has been tested to be effective against Feline Coronavirus. The paper mill, James Cropper was producing the antibacterial paper earlier (since 2006) to serve the hospitals and other places to fight the bacteria and virus, which has helped the Company to accrue adequate experience to upgrade its product to combat the corona virus.

Biomaster technology when applied to paper, has long been proven highly effective against dangerous pathogens such as MRSA and E-coli. In new independent testing, the company's PaperGard protected papers also reduced the viability of the viral strain by over 95% in less than two hours.

Feline Coronavirus and Covid-19 are members of the Coronaviridae family of viruses which cause a broad spectrum of animal and human disease. This group of viruses are enveloped and rely on a protective lipid coating and are amongst the easiest types of virus to deactivate. Biomaster has yet to be tested against Covid-19 on product surfaces and currently there is not yet a commercial method validated for Covid-19.

As indicated in the beginning, corona virus existed before the present deadly virus also. The Coronaviridae family contains many virus, distinguished by different morphology and structure. The silver





ion technology acts very well against its family member, which is the present corona virus.

While PaperGard has been regularly used for the production of medical and healthcare documents, this technology can be applied across the portfolio of paper products manufactured by James Cropper, including papers and boards for premium packaging or greeting cards that are subject to a lot of handling.

This innovation addresses demand for cleaner surfaces. The paper roll is cut into smaller reels and packages for sending to different places and it is absolutely necessary to ensure that each batch contains the antibacterial property to prevent the present corona virus to spread. Simultaneously, it is necessary that the paper exhibits similar appearance and performance as the other papers. The silver ions present within the paper continuously work to prevent the growth of the micro-organisms, effectively reducing contamination levels on the surface.

**New antimicrobial paper line:** American Eagle Paper Mills [19] has introduced a new antimicrobial paper line. The new Eagle Armour suite of paper products has been designed to reduce the transmission of communicable diseases. The paper products have been treated with Biomaster silver ion technology to offer antimicrobial protection for the lifetime of the paper. To address the need for cleaner surfaces, American Eagle Paper Mills has successfully manufactured a paper that incorporates an antimicrobial agent. What is speciality about Eagle Armour antimicrobial paper is that it inhibits the growth of bacteria without sacrificing paper performance or appearance, produces paper with 92% brightness from recycled paper. The new antimicrobial paper products are suitable for use in restaurant and food service facilities. Independent laboratory testing demonstrated a 99.99% reduction in microbes after 24 hours [20].

Biomaster<sup>®</sup> prevents the growth of unwanted microbes that can cause product degradation, discoloration, staining, or odours. It does this by releasing silver ions on demand, preventing microbes from multiplying. The reactions of Biomaster on paper are:

- Biomaster<sup>®</sup> binds to the cell wall, disrupting growth.
- The Biomaster<sup>®</sup> ions interfere with enzyme production stopping the cell producing energy.
- Biomaster<sup>®</sup> interrupts the cell's DNA, preventing replication.

Silver is found in the ore deposits of lead, zinc, copper and gold in the earth, which is extracted by smelting and chemical leaching processes. Since ancient times, silver has been highly regarded as a versatile antimicrobial tool. The antimicrobial properties of silver are most effective at minute concentrations, providing product protection without affecting product performance. Silver provides a durable, non-leachable antimicrobial treatment, unlike organic chemicals.

**Antibacterial face mask:** UK polyurethane engineers Urofoam [21] has developed a unique face mask containing Biomaster technology which can be worn to shield the wearer and those around them against disease-carrying droplets. The product known as dropstop, it is washable and serves as mask at affordable price. It is made from polyurethane foam, a fine matrix of open cells ranging in sizes 200-500 microns thus forming an effective filter medium against much finer particles than the cell size (aerosolised droplets are sub 20 microns).

Dropstop is fabricated in such a contour mould that, it covers tightly the human face and thus it is different from the ordinary masks. It seals all leakages to the face and thus entering of virus to the mouth and nose is minimal. As indicated earlier, it is through the droplets or aerosols that the virus is propagated from person to person and this mask is fabricated in such a way that neither the droplets from the user nor the droplets from outside can flow. It is specially recommended for use by the office staff, those working in the transport sectors and care centres.

**Antimicrobial tissue paper using nanocellulose:** Work on antibacterial tissue paper is going on in NC State's College of Natural Resources [22] and the researchers have opined from their experience that antimicrobial tissue will be right answer against spreading of corona virus. It is based on a hydrophobic spray-coating of Chitosan (Ch) and Cellulose Nanocrystals (CNCs) composite. The experiments have been made at laboratory scale only, where hand sheets were prepared with the nanocellulose and chitosan composite, which was applied onto paper by spray coating and the antimicrobial property was tested against the bacteria *Escherichia coli*. The chitosan-nanocellulose composite-based tissue paper showed inhibition percentage of 98% against the bacteria. On plasma treatment, the antimicrobial property of the tissue paper is enhanced further.

**Disposable tissue paper towel:** Sofidel [23], one of the world's leading manufacturers of tissue paper for hygienic and domestic use, continues to innovate and diversify its solutions for personal and household hygiene. The Company has developed a new disposable tissue paper towel embedded with an antibacterial lotion, which is claimed to be serving effectively.

Generally used in public spaces and workplaces (Away-from-Home), disposable paper towels are now making their entrance into homes, offering a soft, strong and absorbent alternative to fabric towels for drying the hands. Disposable antibacterial towels are designed to retain the germs and bacteria present on wet hands and prevent them from multiplying and the special interfolded dispensing system allows the towels to be taken out one at a time, protecting the product against external contamination.

#### Anti-viral facial tissues

An anti-viral facial tissue [24] is treated with a solution to deactivate cold and flu viruses in cough, sneeze, or nasal discharge to prevent spreading the virus to others. The antibacterial tissue papers are produced in a different way, containing some organic compound based antibacterial agent and it is tested to be effective in its antibacterial activity in the factory. However, when it goes outside and people use it, there are many factors that count on its efficiency of antibacterial property.

The most important point to remember is that once the tissue paper is used, its disposal has to be done properly or else if it has been used by an infected person and just thrown away, it may have adverse effect.

Tissue papers are made up of two-ply and three-ply depending upon the machine conditions. The antibacterial tissue paper is three-ply and its middle layer is treated with the anti-viral formula containing citric acid and sodium lauryl sulphate.

The chemical formula applied in the middle layer of this tissue paper kills all the cold and flu viruses captured, according to the Company.

The packaging for Anti-Viral tissues notes which germs it has



been tested against. It says that it inactivates 99.9% of rhinoviruses type 1A and 2, influenza A and influenza B, and Respiratory Syncytial Virus (RSV) within 15 minutes.

However, the Anti-Viral tissues are not proven to protect against coronaviruses, which cause 10% to 30% of viral upper respiratory infections.

The Company (Kimberly-Clark) explained in its patent made in 1986 that in order to avoid skin irritation by the chemicals, it is applied in the middle layer.

The tissues reached the market in 2003. It was upgraded in 2009 to be used during the swine flu epidemics (H1N1 influenza)

Anti-viral tissues do not kill viruses in or on your body, so they do not shorten the course of illness. In theory, they might reduce the chance that the virus is spread to someone else who might come in contact with the discarded tissue. Colds and influenza are spread in two main ways. First, by droplets spread through the air when one coughs or sneeze, which can travel as far as six feet. Covering our cough or sneeze helps prevent this spread, but it will not eliminate it completely. The habit of using tissue paper is slowly spreading in the Asian countries also as it is soft and convenient to wipe the nose and face. If it is antibacterial tissue, it can ensure reducing the spread of bacteria and virus.

Viruses are also spread by droplets settling on surfaces or virus being transferred to surfaces from our hands that are contaminated by our own respiratory secretions. A cold virus can live outside of the body or on a hard surface for three or more hours.

If one uses the tissue and cannot dispose of it immediately, it is possible that the anti-viral tissue would deactivate the virus, so the tissue would be less infective to others who would come in contact with it. However, it may be noted that these tissues do not deactivate the viruses on our hands or face, as the sides that touch our skin are not treated with anti-viral formula. One still needs to wash the hands well after using the tissue to avoid spreading germs.

The infection due to the used tissue paper depends how long before it was thrown.

### Demand for Antiviral Packaging to increase

The coronavirus pandemic continues to rewrite the nature of global society in 2020, and with it the attitudes and behaviours of consumers now and for the foreseeable future [25]. The fear of infection due to different bacteria and virus, will raise the demand of antibacterial tissue papers. The present corona virus epidemic has thrown challenges for innovations.

The demand for heat-treated aseptic packaging is likely increase because of the demand for UHT (Ultra high temperature) processed products.

In food packaging, the two prominent research areas are now on antibacterial and antiviral polymers and biopolymers and the results are encouraging.

Demand for such materials in day-to-day consumer products may rise significantly post-Covid-19, as consumers are likely to maintain concerns and habits learnt during this difficult period.

### Antibacterial personal care wipes market

Anti-bacterial personal wipes are used for cleaning and for disinfectant purposes. These can be in folded or wrapped forms.

They are made of tissue, paper, or nonwoven and contain antibacterial ingredients which are effective at killing 99.9% of harmful germs [26].

Most of the presently available antibacterial personal wipes in the market are efficient in cleaning away the virus and bacteria.

Leading companies are focused on offering gentle Antibacterial Personal Care Wipes biodegrade in 28 days and are made of 100% renewable plant fibres to ensure that no waste is generated that might pollute the environment. Therefore, the development of new and innovative biodegradable Antibacterial Personal Care Wipes is projected to provide a huge growth opportunity for the key players operating in the market during the forecast period.

Based on product types, the anti-bacterial personal wipes market is segmented into sanitizing, skincare, and wound cleaning. The sanitizing segment held the largest share of the market in 2019 and is estimated to register the highest CAGR in the market during the forecast period; *at a CAGR of 9.3% from 2019 to 2027.*

### Technology Problem in producing antimicrobial paper in the manufacturing process- Embedding the Nano particles on paper

One of the likely problems, to be faced in the manufacturing of antimicrobial paper in the paper mill is how to incorporate the nano particles onto the paper or board. There could be many techniques for manufacturing of the antimicrobial paper. Incorporation of the antimicrobial nano particles such as Ag (silver), which may be available in ionic form ( $Ag^+$ ) or reduced metallic form ( $Ag^0$ ). This nano material being quite costly, one cannot afford to add anywhere and any amount in the manufacturing process.

**During stock preparation:** It cannot be added at the stage of stock preparation because one cannot ensure that the trace amount of additive, will adhere to the paper surface.

**During surface sizing:** At the stage of size press, one may add but it has to be experimented thoroughly; the other safe stage where it can be added, is during coating. So, the 1<sup>st</sup>thing to be sorted out is at which stage it is to be added. A metered size press could serve the purpose appropriately. However, if a suitable engineered pigment with functional properties, can be developed, it may be possible to add it along with the other chemicals in the size press.

**During coating:** Addition of the the antimicrobial nanoparticles as such alone cannot result in uniform distribution on the coated surface; it has to be mixed in the other coating formulation so that the resulting paper imparts the antimicrobial property for whole life period or long period. Laboratory trials should be taken to optimise the functional properties and minimising the cost of antimicrobial additive as well as for uniform distribution. The important aspects in the laboratory trials are:

- ◆ the concentration of antimicrobial additive,
- ◆ compatible chemicals in the formulation,
- ◆ compatible mineral pigment in the coating formulation and
- ◆ mixing parameters.

All the above factors can be decided after repeated laboratory trials in a small coating machine first before the mill trial.

The metallic ions possessing the antibacterial property are based



on the metals such as silver, copper, and zinc, which are impregnated on to a mineral pigment and then applied as a composite material to the paper. The mode of applications can be:

- (a) With regular coating pigments: It can be embedded in some mineral or coating pigment regularly used in coating, namely calcium carbonate (precipitated or ground), titania, kaolinite clay or talc mineral.
- (b) With other clay minerals (Vermiculite and montmorillonite): Extensive studies were carried out to exchange the metallic ions in the interlayer spaces of clay minerals such as vermiculite [27] and montmorillonite [28].
- (c) Attempts may be made to find out compatible chemicals and appropriate coating formulation to incorporate the silver ions with the regular pigments used in the paper coating, such as kaolinite clay, calcium carbonate and titania [29].
- (d) Zeolite and few other synthetic products can also be loaded with the antimicrobial agent.

Inorganic antibacterial material such as silver ions are to be added in traces and therefore these are impregnated or mixed with other additives and then applied to paper. The above inorganic antibacterial additive is safe to use because it is not volatile like the organic compounds, often used as antibacterial agent in the tissue paper and other products.

The release of antibacterial effect from the metallic ions on the surface of the paper, inhibits the growth of microbes. When the microbes come in contact with the antibacterial silver ions, they get bonded ending up with death as they cannot create enzymes.

Silver ions are thought to inhibit bacterial enzymes and bind to DNA. The silver ion technology has been found to be working effectively against all types of micro-organisms such as bacteria, fungi and viruses.

Silver has a broad spectrum of antibacterial activity, while exhibiting low toxicity towards mammalian cells [30].

By impregnating silver or copper ions into the nanometre openings between the layers of vermiculite, it is possible to render the composite with antibacterial functions if the copper ions can be released gradually from the composite.

The minimum concentration of silver ions to inhibit *Escherichia coli* has been found to be as low as 0.78µg/ ml. The antibacterial silver ions are added with other minerals and compounds such as zeolite, glass, zirconium phosphate, phosphorite and titania.

These products generally show high antibacterial activity and low toxicity. However, the high reactivity of silver was found to be a problem. Examples include the reduction of silver ions to elemental silver, causing the loss of antibacterial ability, and the change to dark colour after ultraviolet irradiation or heating of the composite.

- (e) with kaolin: Kaolin has some antibacterial properties and is used to absorb toxins and bacteria like the other clays. New multifunctional materials possessing antibacterial and antifungal properties have been derived from clay minerals and other inorganic materials by using cation exchange reaction and surface modification [31,32].

As indicated at the outset, though the technology of producing antimicrobial paper, is now applied at industrial scale, it is still a secret subject. However, R & D organisations should start putting their efforts on this product development for mass scale production of antimicrobial paper as spread-breaker for Corona virus.

## CONCLUSION

There exists lot of confusion on the Antimicrobial products meant for different micro-organisms to reduce proliferation and spread of diseases caused by bacteria and viruses. While there are some antibacterial products and paper developed for Methicillin Resistant *Staphylococcus aureus*(MRSA) and even SARS CoV-1, there has only been a beginning made to combat the present corona virus (SARS CoV-2).

The antimicrobial paper can be divided into two categories in terms of the antimicrobial additive used and the efficiency; the antimicrobial tissue paper, where mostly organic compounds are added with efficiency lasting for short duration and specific use; the second is the Ag- and other nanoparticles based antimicrobial product, which can impart antimicrobial property life-long and specifically meant to kill the corona virus.

The Ag-ion based antimicrobial paper has been tested to be working very well, reducing the CoV-2 to > 95% from the paper surface. Two paper industries (one in UK and one in USA) have already started producing antibacterial papers at industrial scale for use in hospitals, packaging, school stationary, restaurants etc.

The antibacterial additives for the tissue paper, are mostly organic compounds, applied in the middle layer surface. While the tissue papers can serve to reduce bacteria and virus at the time of sneezing or coughing, these cannot reduce the spread of present corona virus infection; rather caution should be taken in disposing of the used tissues.

Efforts for application of nanotechnology in producing appropriate antibacterial papers, should be intensified as many metallic and oxide nano materials are available. These have been tried extensively for producing multitude of materials for use in all domains and it is high time to intensify research to incorporate them for production of efficient antibacterial products.

The demand for antibacterial paper and products is likely to increase in future because of the impact of corona virus inculcating use of safe and hygienic products with antibacterial properties.

It is proposed that the antibacterial nano particles should be incorporated to the commonly used pigments for coating or in some clay minerals such vermiculite and montmorillonite and the composite product to be added at the stage of surface sizing or coating.

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## DISCLAIMER

Many information are collected from the website or as received from the Organisations. The author takes no responsibility on the claims made.



## REFERENCES

1. Mahendra Patel. Nanoparticle-based antimicrobial paper as spread-breaker for corona virus. Paper Technology International (UK). 2020; 62: 20-25.
2. van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med*. 2020; 382: 1564-1567. DOI: 10.1056/NEJMc2004973
3. National Inst. Health (NIH). New coronavirus stable for hours on surfaces: SARS-CoV-2 stability similar to original SARS virus. March 17, 2020. <https://bit.ly/2Co4a25>
4. NIH Research Matters. Study suggests new coronavirus may remain on surfaces for days. March 24, 2020. <https://bit.ly/2Olajsl>
5. Personal correspondence. NIAID (The National Institute of Allergy and Infectious Diseases, National Institutes of Health, United States Department of Health and Human Services). June 23, 2020. <https://bit.ly/2ZLqyen>
6. Mahendra Patel. Developments in antibacterial paper. Industry Insights, PIRA International. 2009.
7. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med*. 2014; 370: 1198-1208. DOI: 10.1056/NEJMoa1306801
8. Mahendra Patel. In micro and nanotechnology in paper manufacturing. Antibacterial paper, Ch. 25. Publ. Industypaper, New Delhi (2009).
9. Formulations for COVID-19 treatment via silver nanoparticles inhalation delivery Oron Zachar. Researchgate. June, 2020.
10. Galdiero S, Falanga A, Vitiello M, Cantisani M, Marra V, Galdiero M. Silver nanoparticles as potential antiviral agents; *Molecules*. 2011; 16: 8894-8918. DOI: 10.3390/molecules16108894
11. Siadati SA, Afzali M, Sayyadi M. Could silver nano-particles control the 2019-nCoV virus; An urgent glance to the past. *Chemical Review and Letters*. 2020; 3: 9-11. DOI: 10.22034/CRL.2020.224649.1044
12. Nakamura S, Sato M, Sato Y, Ando N, Takayama T, Fujita M, Ishihara M. Synthesis and application of Silver Nanoparticles (Ag NPs) for the prevention of infection in healthcare workers; *Int J Mol Sci*. 2019; 20: 3620. DOI: 10.3390/ijms20153620
13. Tran QH, Nguyen VQ, Le AT. Silver nanoparticles: synthesis, properties, toxicology, applications and perspectives. *Adv Nat Sci Nanosci Nanotechnology*. 2013; 4: 033001. <https://bit.ly/39nN2pi>
14. Technology against Covid-19: Nano insights into prevention, diagnosis, and treatment. <https://bit.ly/32Jds3n>
15. Vuk Usković. Why have nanotechnologies been underutilized in the global uprising against the coronavirus pandemic? *Nanomedicine (Lond)*. 2020. DOI: 10.2217/nnm-2020-0163
16. Personal correspondence, Dr. Sandrine Garnier, Managing Director & Paul Morris, Founder and CEO Addmaster (UK) Ltd, June (2020) & [www.addmaster.co.uk](http://www.addmaster.co.uk)
17. Anti-Bacterial Print Services. June 22, 2020. <https://bit.ly/3jtxUeF>
18. Covid-19: James Cropper papers effective against Feline Coronavirus. June 8, 2020. <https://bit.ly/2Cw4UIP>
19. American Eagle Paper Mills introduces new antimicrobial paper line. May 12, 2020. <https://bit.ly/2ZTz2Ad>
20. Antibacterial paper: Eagle armour. [www.aepaper.com](http://www.aepaper.com)
21. Dropstop with Biomaster, the antimicrobial face mask, e-newsletter. June 21, 2020. <https://bit.ly/30FLYJd>
22. Andrew Moore. Antimicrobial tissue paper could help fight the spread of COVID-19 and other infectious diseases. March 30, 2020. <https://bit.ly/32PVpIK>
23. Tyagi P, Mathew R, Opperman C, Jameel H, Gonzalez R, Lucia L, et al. High-strength antibacterial chitosan-cellulose nanocrystal composite tissue paper. 2019; 35: 104-112. DOI: 10.1021/acs.langmuir.8b02655
24. Press release, Porcari (Lucca, Italy). May 26, 2020. <https://bit.ly/2E6iBYU>
25. Duda K, Collins R, Are anti-viral tissues worth using? April 17, 2020. <https://bit.ly/39tzlVO>
26. The demand for sterile and antiviral packaging amid Covid-19 panic, Packaging Gateway. March 23, 2020. <https://bit.ly/39mpy3z>
27. Asia Pacific antibacterial personal care wipes market forecast to 2027 - COVID-19 impact and regional analysis by product types; distribution channel; and Country. *Globe Newswire*, New York. June 22, 2020. <https://bit.ly/2OMBmOK>
28. Patel M, Kermarec M, Pezerat H, Etude thermique de la vermiculitechange'e au nickel. *Compte Rendu Acad Sci. Paris*. 1981; 290C: 279-299.
29. Patel M. Reduction of Ni(II) and Cu(II) in montmorillonite with hydrogen. *Clays & Clay Minerals*. 1982; 30: 397-399.
30. Patel M, Tripathy DK, Improvement in coating performance with modified talc. *IPPTA J*. 1997; 8: 31-35.
31. Guoyu LV, Yubao LI, Aiping Yang, Xiang Zhang, Weihu Yang and Jidong Li. Preparation and antibacterial activity of silver ions substituted hydroxyapatite/titania. *Mat Sci Forum*. 2006; 510-511: 78-81. <https://bit.ly/2EcA2aq>
32. Bowen Li, Shuhui Yu, Jim Y. Hwang, Shangzhao Shi, Antibacterial vermiculite nanomaterial. *J Materials and Material Characterisation & Eng*. 2002; 1: 61-68.