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Antimicrobial processing techniques for fabric enhancement

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Abstract

Microorganisms and microbes may cause a loss of tissue properties, so antimicrobial processing must be done. There are many techniques that can be used in the processing process and applied to fabric to impart antimicrobial properties, including the super critical. In this method, water is not used, but carbon dioxide is used instead. Supercritical, thus reducing water consumption and preserving the environment from pollution. Super critical is applied to different types of fabric, whether cotton or polyester. Plasma can also be used in anti-bacterial processing, where there is a thermal and non-thermal plasma. In this processing, atmospheric pressure plasma and plasma (PDP) can be used on various materials to improve the loading of antibacterial agents on the material and thus increase the ability of the material to resist bacteria. Finally, the microencapsulation method can be used, whether in micro or nano size, and it consists of a core, which is the basic material, and a shell, which is. Herbal plants are extracted and used as a base material in the capsule and their release is controlled to increase the material's resistance to microbes.

Keywords: Finishing, plasma, capsulation, antimicrobial, supercritical

Introduction

Fibers are commonly used in both medical fields and all aspects of human life. [1, 2] However, because of its large surface area and superior moisture holding capabilities, natural fibers are more probable to become colonized by microorganisms. [3]

Microbes are a common occurrence in our daily life. Microorganisms can be of two types: beneficial and harmful. Numerous microbes may be discovered on our bodies and in the environment. The natural characteristics of textile fibers allow for the growth of microbes. Also, microbial growth can be promoted by the chemical processes and the substrate structure. Warm, humid conditions keep aggravating it. Microbe infestation leads to pathogen infection and the growth of smell when the cloth is worn close to the skin. Additionally, microbial attack is the cause of textile substrate coloration and loss of performance characteristics. In general, textile materials are treated with antimicrobial agents to protect both the consumer and the textile substrate.[4-10]

Usually, antimicrobial agents are used in the finishing phases of the textile production process. Some synthetic antimicrobial agents, like triclosan, are prohibited, mainly those that are non-biodegradable and have the potential to irritate skin. The eco-friendliness of natural antimicrobial agents, such extracts from neem, aloe vera, eucalyptus, etc. received a lot of interest lately. Although natural antimicrobial compounds have been shown to have broad-spectrum behavior against viruses, fungi, and bacteria, their durability and efficiency are still rather limited.[3, 11, 12]

Natural antimicrobial agents

The discovery of new chemicals with antimicrobial activity from natural sources has progressed significantly. Marine and terrestrial organisms, including fungus and bacteria, as well as medicinal plants are recognized sources of natural chemicals possessing significant antimicrobial

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activity. Recently, a great deal of study focus has been focused on plants as an important source of organic antimicrobials. Research has been done on materials that have been extracted from various plant parts, including the bark, leaves, roots, and flowers. These materials contain common dyes including tannin, flavonoids, and quinonoids, which also have effective antimicrobial properties.[3, 8, 9, 13-16]

Antimicrobial finishing

Not all antimicrobials function in the same way. Most antimicrobial agents function through the process of leaching or migrating from the surface they are applied on. This is the method by which leaking antimicrobial agents poison a microbe. An unconventional technology called an organofunctional silane is an antimicrobial that acts entirely differently from leaching technologies. Its mode of action depends on the technology staying attached to the substrate, which kills microorganisms as soon as they meet the surface it is applied to. This technology's effectiveness does not fade or weaken with time. When used, the technique truly causes the substrate to polymerize, giving the surface an antimicrobial effect. Textiles that are likely to come into touch with humans are treated with this kind of antimicrobial technology. [4, 6, 7, 10, 11, 17-23]

Four primary goals may be suggested from the use of antimicrobial finishes:

1. decreasing the odors that occur from the microbial degradation of perspiration.
2. to prevent the transmission and growth of harmful microbes.
3. to prevent microbial Fiber degradation from inducing a loss of performance properties.
4. to greatly decrease the quantity of bacteria.[24]

Mechanism of antimicrobial activity

Numerous fabrics with antimicrobial finishes behave according to their type of diffusion. The efficiency of the finish is directly impacted by the rate of diffusion. For instance, the ion exchange mechanism has less impact than direct diffusion because the active chemicals are released at a lower rate. Comparably, antimicrobial modifications are less effective since the active ingredients are not released from the Fiber surface. Only when they come into touch with microorganisms do they become active. Based on its ability to resist germs, antimicrobial fabrics may be divided into two groups: passive and active. While the surface structure of passive materials (the Lotus effect) negatively affects the living conditions of microorganisms (the Anti adhesive effect), the materials themselves do not contain any active substances.[4]

Techniques that used in antimicrobial finishing

Super critical

Super critical fluid

Supercritical fluids (SCF) are systems that include gases at high temperatures and pressures. Liquids can become supercritical fluids and low-to-medium polarity organic molecules dissolve when these systems reach critical point values, particularly temperature and pressure. The super critical fluid has both properties and is neither a gas nor a liquid. In contrast to the gaseous state, where a supercritical fluid's density is 200–400 times greater. Relatively slight modifications to temperature and pressure may easily affect the density of a supercritical fluid. The double beneficial properties of high density and high compressibility are shown by these fluids.[25]

Supercritical Carbon Dioxide

Supercritical carbon dioxide ($scCO_2$) is the most widely used supercritical fluid in the industry due to its numerous advantages including its low cost, nontoxicity, nonflammability, and chemical inertness under a variety of conditions. As a supercritical fluid, carbon dioxide has a critical point of 31.1°C and 73.8 pressure. Since supercritical carbon dioxide is both diffusive like gases and solvent like liquids, it may be considered as an expanded liquid or as a huge amount of compressed gas. This makes it suitable for reaction conditions. Because of its low critical temperature and critical pressures and relatively easy operation, this technique is ideal for a variety of textile applications. In its supercritical fluid phase, ecologically benign carbon dioxide offers potential in place of the current reliance on a variety of dangerous, comparatively expensive, and harmful organic solvents. [25-30]

Application of $scCO_2$ in antimicrobial finishing

Antimicrobial finishing of cellulose with QSA silicone by supercritical adsorption

It has been proven that chemicals containing QAS groups can stop a variety of microbes from growing by interacting with the cell membrane and inactivating proteins. Also, QAS groups affect the DNA of microbes, limiting their capacity for replication. Consequently, biological activities associated with the cell membrane and DNA are destroyed, leading to the death of microorganisms. Consequently, QAS compounds are commonly utilized biocides that have been added to common materials to accomplish biocidal function. There are

two types of current ways for attaching antibacterial agents with QAS groups to materials: physical methods and chemical methods.

The physical method absorbs antibacterial agents onto surfaces by use of weak forces such as electrostatic attraction and hydrogen bonding. Because of the antimicrobial agents' short-term activity, these material modifications become limited. Covalent bonds are used in the chemical method to attach QAS substances to substrate surface reactive groups by chemical reactions. Chemical tethering has a long-lasting biocidal effect; however, processing becomes more complex due to the many chemical reactions needed to create biocidal surfaces. In addition, surfaces of substrates may not always have the necessary functional groups for the required covalent conjugations or be able to generate them.

Any chemical moiety that makes a desired function is referred to as a functional group definition. Functional polymers provide desired interfacial characteristics at surfaces when they are coated on materials. The process generated long-lasting surface characteristics without requiring the functional polymers to be covalently bonded to the substrates. While the functional groups arrange themselves on substrate surfaces to provide the required interfacial characteristics, some of the functional polymer attaches into materials to provide stable interpenetration. Spin-coating the functional polymers onto substrates is a simple process. It has been demonstrated that functional polymers may be adsorbed onto substrates of arbitrary shape using supercritical fluids, which mostly consist of CO2. CO_2 is used in this modification method in place of traditional solvents.

Other advantages of the scCO2 coating process are that excess functional polymer precipitates out after deposition and can be recycled without the need for difficult recovery steps, The scCO2 critical point is easily reached, and the dissolving power of scCO2 can be easily adjusted by modifying its temperature and pressure.

The study showed how to create long-lasting antimicrobial effects on cellulose in an easy method without the need for covalently bonded tethering groups, which limit structural design. Through the hydrosilylation of poly(methylhydrosiloxane) (PMHS) and 2-(dimethylamino) ethyl acrylate in the presence of a platinum-based catalyst, followed by quaternization with 1-bromohexane, CO2-philic silicone with quaternary ammonium salt (QAS) pendants were formed. Supercritical CO2 (scCO2) was adsorbed onto cellulose to generate the resulting QAS silicone. [31]

Using sustainable biopolymers (chitosan/ derivative) as eco-friendly antimicrobial agents via the (scCO2) dyeing route in a single step

As an antimicrobial finishing agent applied to various textile fibers, chitosan and its derivatives have been thoroughly researched due to its proven antimicrobial action against a wide variety of microorganisms. However, the effectiveness and durability of these natural antimicrobial agents are typically limited. Therefore, efforts to find appropriate application techniques that will impart high effectiveness and durability are currently ongoing. Furthermore, with talking about chitosan particularly, a major limitation of applying chitosan via conventional methods is that its effectiveness is limited to higher concentrations, at which point it forms a film on the fabric's surface that reduces air permeability and stiffens it. Given that a lower level of concentration is often used, $scCO_2$ dyeing may be an appropriate method for applying chitosan to fabrics in this way. Furthermore, a few chitosan derivatives including low molecular weight chitosan have demonstrated some solubility in $scCO_2$. Also, it was shown that chitosan with lower viscosity and molecular weight was more able to penetrate the fiber structure than chitosan with a higher molecular weight.

The idea was that, to produce a high-performing and long-lasting product, chitosan types with extremely low molecular weight and viscosity could either fully or partially penetrate the swollen polymer matrix and then incorporate into the fiber cavities during the last CO2 depressurization step. Therefore, the purpose of this study was to determine if it would be possible to create antimicrobial polyester fabric in a single step utilizing the scCO2 dyeing technique.

The disperse dye and chitosan/derivative were added to a $scCO_2$ solution to dye polyester fabric. The color property and antimicrobial activity of the treated samples were analyzed to determine the compatibility of the dye and antimicrobial activity. There were two methods applied: Without any modifications, the cleaned original polyester was utilized in the first one. While modified polyester with an anchoring agent was used in the second method, disperse dye and a common chitosan type were utilized in both situations.

A modest amount of dye was used to dye the polyester fabric for one hour at 120°C in the presence of chitosan or a derivative in $scCO_2$. Using (FTIR) and (SEM), the efficacy of chitosan/derivative impregnation was verified. The treated samples generated outstanding hue and fastness characteristics, and after one hour, they eliminated 75−93% of the E. coli (ATCC 25922) bacteria. there was no negative interaction between the dye and the chitosan/derivative, demonstrating their compa-tibility. With this new technique, the

manufacturing costs and environmental damage caused by the traditional textile finishing methods would be decreased.[32]

Impregnate polyester (PET) fabric with chitin and chitosan

Supercritical carbon dioxide was used to impregnate polyester (PET) fabric with chitin and chitosan to produce strong antibacterial properties that withstand washing. Polyester fabric was successfully treated with chitosan-lactic acid salt in supercritical carbon dioxide medium. However, chitin could not bear effective impregnation.

Here, polyester fabrics kept 70% of its chitosan even after 50 home washing cycles, meaning that their antimicrobial properties were maintained. It is well recognized that permanently impregnating polyester fabric with chitosan in an aqueous solution is extremely hard.

Also, it is essential to mention that chitosan may be permanently fixed by strongly impregnating polyester fabric using supercritical carbon dioxide.[25]

Using Silver Deposition in $scCO_2$

It was demonstrated that $scCO_2$ processing is an effective technique to generate textiles with antifungal properties that might be applied in medical applications. Even though the study's sample sizes were small, $scCO_2$ processing may readily be expanded for the fabrication of silver-coated textiles on a commercial scale.

Ag(hepta) and Ag(cod) (hfac)-modified textiles showed measurable zones of inhibition. Conversely, there was no zone of restriction on the uncoated fabrics.

There are several benefits to using $scCO_2$ to provide products antibacterial properties, including comparatively low processing temperatures, nonflammable processing materials, and nontoxic reactants. Textiles used in wound dressings may be given antifungal properties by supercritical CO_2 processing.

To stop the spread of fungal diseases in hospitals, nursing homes, and other healthcare settings, hospital uniforms with antifungal fabrics may be utilized. [33]

Impregnation of corona modified polypropylene non-woven material with thymol

To create environmentally friendly antimicrobial textile material, the prospect of impregnating polypropylene (PP) and corona modified PP non-woven material with thymol in supercritical solvent is considered. The fluid that was utilized was carbon dioxide. FESEM examination showed the presence of thymol on the fiber surface during impregnation and the morphological changes on the PP fiber surface caused by corona treatment at atmospheric pressure. Analyses using FTIR were used to evaluate chemical changes. The modified polypropylene non-woven material's antimicrobial activity was evaluated against the fungus Candida albicans, the Gram-positive bacteria Staphylococcus aureus, and the Gram-negative bacterium Escherichia coli. The greatest microbial reduction was achieved by both PP non-woven material impregnated with thymol and corona activated PP impregnated with thymol; however, the material that was pre-treated with corona was much more quickly wetted, which may be helpful for wound healing.[34]

Plasma

Plasma is a type of ionized gas that includes numerous charged particles (OH–, H2O+, electrons), reactive chemicals (superoxide anion hydrogen peroxide, reactive nitrogen species), excited and basic state molecules, and UV–Vis photons. Plasma is proposed to be the fourth state of matter. [35-38]

Three typical frequencies can be used to create plasma: microwave (915 MHz or 2.45 GHz), radio frequency (13.56 or 27.12 MHz), and low frequency (50–450 kHz). [39]

Two types of plasma exist:

1) thermal or equilibrium plasma.
2) non-thermal or non-equilibrium plasma.

At 4000 K or more, thermal, or hot plasmas are thought to be in a state of thermal equilibrium, in which the temperatures of the heavy ions and electrons are equal. Thermal plasma chemical vapor deposition (TPCVD), thermal plasma synthesis of fine powders (nm), and plasma spraying are well-known applications.

Only the electrons are accelerated in non-thermal or cold plasma, for example, by an applied electric field, which results in a thermal in equilibrium between the electrons and the heavier particles. At lower temperatures, plasma forms consequently.

Thermal and non-thermal plasmas operate at different temperatures, which is why they are frequently referred to as "hot" and "cold" plasmas, respectively. Despite being called cold plasma, temperatures as high as 1000 K are achievable.[40] Non thermal or cold plasmas are frequently used in a variety of textile applications. Either vacuum pressure or atmospheric pressure is used in textile plasma techniques. [41]

The benefit of using plasma to functionalize textiles

Plasma is particularly special for textile functionalization because of the following characteristics:

1) Maintain and enhance adherence.
2) Characteristics of sterilization
3) Because plasma is sprayed at a low temperature, there is a decrease of fabric exposure.
4) Clean the fiber's outer surface to eliminate any small amounts of organic impurities.
5) It is an environmentally friendly option due to plasma dry processes.

Textile surface layers undergo structural, chemical, and other changes because of the effects of plasma treatments on fiber and polymers. [41]

Plasma's Effect on Textiles and polymers

When textile materials are treated with plasma, they experience significant chemical and physical changes, such as: (1) modifications to the surface layers' chemical compositions; (2) modifications to the structure of the surface layers; and (3) modifications to the surface layers' physical characteristics.

Free radicals are generated in large quantities by plasmas because of electron collisions and photochemical reactions that separate apart molecules. The fiber polymer surface's chemical bonds are disrupted as a result, leading to the formation of new chemical species. The specific surface area of fiber increases significantly, and both surface topography and surface chemistry are impacted. [42]

1) New functional groups, such as hydroxyl (-OH) and carboxyl (COOH), are formed when fiber and polymer surfaces are plasma treated. These groups affect the fabric's weight and allow for graft polymerization. During the plasma treatment of fibers and polymers, the surface of the substratum is actively interacting with the energetic particles and plasma photons, usually using free radical chemical methods. On surfaces, there are typically four main effects:
2) Plasma cleaning and etching signifies eliminating impurities or substrates from the material's exposed surface.
3) Plasma activation: New functional groups are attached to the surface that has been treated. The presence of the chemical groups affects the surface characteristics.
4) The two-stage technique known as "plasma-assisted grafting" involves the activation of plasma followed by exposure to gas or liquid precursors like monomer. There is a conventional free radical polymerization in the monomer on the active surface.
5) In plasma polymerization, the plasma itself is polymerized as soon as a monomer is injected into it. [41]

Applications of plasma treatment in antimicrobial finishing of textiles

Polymerization and grafting of antimicrobial substances

In contrast to conventional methods like pad-dry-curing, which are used to graft different compounds onto textiles, plasma treatment can activate the substrate and monomers to initiate the grafting reaction without the need for heating or immersion in a chemical bath, saving energy and water, as well as reducing pollution to the environment.

With the use of plasma, polymerizable precursors such vinyl, aromatic, cyclic, and saturated hydrocarbons, as well as metalorganic compounds, can be directly polymerized on a substrate's surface. Surface activation can be achieved by using reactive gases (like O_2 or N_2) or non-reactive gases (like Ar and He) if the polymerizable precursors can't be used directly in the plasma chamber.

When energetic species in the plasma medium collide with the substrate's polymeric chains, free radicals form on the surface. [43]

Antimicrobial agent loading is enhanced by surface activation

One quick and affordable pretreatment method for encouraging the loading of non-polymerizable antimicrobial agents on textile substrates is surface activation or functionalization by plasma treatment.

Antimicrobial agents, including QACs, nanoparticles, and medicines, regularly show poor loading and fastness properties on textiles, particularly those composed of hydrophobic fibers. Textile fibers require surface treatment to increase their wettability, surface tension, and reactivity. [43]

Plasma pretreatment on cotton fabric and using MF, MB

To help apply an antimicrobial method on cotton fabric with high functional impact, the plasma can be utilized as a pretreatment step. The cotton fabric will be treated with an antimicrobial finishing agent, Microfresh Liquid Formulation (MF), and a binder, Polyurethane Dispersion, Microban Liquid Formulation (MB), to enhance its antimicrobial properties. Additionally, pre-treating the cotton fabric with plasma under atmospheric pressure will improve the loading of chemical agents.

Furthermore, textiles that have just been pre-treated with oxygen plasma have the potential to

further improve their anti-microbial properties since the plasma gas contains reactive oxygen species that can attack cells and ultimately result in their death. When the specimens were treated with MF-MB, the hydrophilic carbonyl groups that were present in the oxygen plasma prepared specimens also enhanced the antimicrobial activity.

The chemical composition of the textiles was examined using FTIR. The MF-MB treated substance showed two distinct, strong hydroxyl stretching bands, each of which indicated the presence of triclosan on the textiles. The cotton fabric that had been plasma pretreated had more MF-MB chemical agents than the cotton fabric that had not been plasma treated, according to the FTIR result. Thus, it could be concluded that plasma pre-treatment might improve cotton fabric's absorption of antimicrobial finishing agent, increasing cotton's antimicrobial ability.[44]

Plasma pretreatment on surgical gowns

These days, a lot of textile surface modification techniques, such plasma treatment, are used for generating long-lasting antimicrobial fabrics. is a nonwoven fabric that is used to make surgical gowns. To provide it dual functionality—blood and microbe repellency—it has been treated with fluorocarbon plasma and an antimicrobial finish.

By using plasma preprocesses in graft copolymerization, biocidal polypropylene has been synthesized. Plasma has been used as a preprocess to roughen the surface of cotton fabric, making it easier to load larger amounts of zinc and silver oxide. To give the fabric a biocidal efficacy, these oxides were employed as a catalyst to promote the reaction between halogenated phenoxy compounds, and a binder called Microban. [45]

Plasma treatment on blend military fabric

To create a durable antimicrobial network, a 50/50 nylon cotton blend military fabric has been treated with atmospheric pressure glow discharge plasma to generate free radicals on the surface. This allows the fabric to form a graft polymerized network upon contact with diallyl dimethyl ammonium chloride monomer and pentaerythritol tetra acrylate (PETA), a cross-linking agent**. [45]**

Treatment of PET using atmospheric pressure plasma

Three steps have been taken to prepare an antimicrobial nano-silver non-woven polyethylene terephthalate (PET) fabric. Using an atmospheric pressure plasma system, an organosilicon thin film layer was initially applied to the textiles as a pretreatment. Next, silver nanoparticles (AgNPs) were incorporated into the fabrics by a dipping-dry process, and lastly the nanoparticles were coated.

The shape and chemical composition of the nano-silver textiles have been studied using a variety of surface characterization methods, such as SEM. These methods have led to the observation of an even immobilization of AgNPs in the PET matrix. Tests have also been conducted on the treated textiles' antimicrobial properties. It demonstrates that the barrier layer's thickness has a significant impact on the fabrics' ability to reduce germs.

In a washing procedure, the AgNPs' durability and stability on the textiles have also been studied. By doing this, it is established that the barrier layer can successfully stop AgNPs from releasing and that an important factor to limiting the release of silver ions is the barrier layer's thickness.[46]

Using the GMA with plasma atmospheric pressure

Using plasma atmospheric pressure for active monomers during copolymerization, we create antimicrobial preparations on cotton textiles. The procedure involves many steps: first, tissue samples are surface activated using plasma atmospheric pressure; next, the polymerization reaction of glycidyl methacrylate (GMA) is injected; finally, GMA is grafted onto the material's surface. Desire interacting with a tetra ammonium chitosan derivative or B-cyclodextrin, two antibacterial agents**.** [47]

Using the LTP with Cu particles

In dry systems, low temperature plasma (LTP) is a helpful method for surface-modifying polymers and textile textiles. A DC magnetron sputtering method was employed to provide cotton textiles with antimicrobial properties. Samples were put on the anode of a copper cathode and anode. Attacking electrons, radicals, and active ions scattered the cathode particles. Cotton samples were coated with copper particles, and by incorporating copper particles into fabric surfaces, an antibacterial was created. The materials' surface concentration of copper was linked to their antimicrobial properties. Following plasma treatment, textile technology testing and surface analysis techniques were used to evaluate the materials' chemical and physical characteristics. The Halo approach was also utilized to measure the antibacterial effectiveness. According to the experimental results, some textile items may benefit from the modifications in characteristics brought about by LTP. [48]

Capsulation

Using the effective method of microen-capsulation, active compounds can be contained at the micro- or nanometric scale in a polymeric membrane or matrix to protect them from external

factors, maintain their reactivity, and enable their release when the intended conditions are met. A little part of an active material enclosed in an encapsulating agent with micro- or nanoscale dimensions, is known as a micro- or nano capsule because it separates the active material from the surrounding medium. Either a liquid or solid form of the active ingredient is available. The active components are surrounded by what is sometimes referred to as the wall, shell, exterior phase, membrane, or matrix—a polymer covering. It might be a synthetic, semi-synthetic, or natural polymer. [49-54]

The form of micro/nano capsules is significantly influenced by the kind of core material. Spherical capsules are produced by liquid droplets forming an irregular shape around a solid or crystal core. As extremely fine core materials are evenly dispersed throughout the wall material, a variety of particles or matrix can also occur. It is also possible to make multi-wall or multi-core micro/nano capsules.[55]

Microencapsulation Methods

While several methods for microencapsulation have been documented, they may be generally classified into two primary categories. Methods using monomers or prepolymers as starting ingredients come in the first group. These techniques involve not only the creation of microspheres but also chemical processes. Methods using polymers as starting materials come in the second group. Therefore, these techniques solely involve the production of shapes and do not require any chemical processes.

The type of polymeric or monomeric material being employed determines which microencapsulation technique is suitable. As a result, a wide range of compositional and morphological properties of microencapsulated products can be produced by selecting the right starting materials and synthesis techniques.[56]

The processes of in situ and interfacial polymerization

Reactive monomers polymerize on the surface of a droplet or particle to create the capsule shell in interfacial polymerization. The liquid core material dissolves a multifunctional monomer. The resultant solution is mixed with an aqueous phase containing a dispersion agent until the drop size is as small as required. The aqueous phase is subsequently added with the aqueous coreactant, which is often a multifunctional amine.The capsule shell is eventually created at the interface by a quick polymerization process. Interfacial polymerization processes can encapsulated both liquids and solids, however the chemistry of the polymerization is usually different.

Similar to interfacial polymerization, in-situ polymerization produces capsule shells by the polymerization of monomers introduced to the encapsulation reactor. Reactive agents aren't, however, added to the core substance. Only in the continuous phase and on the continuous phase side of the interaction created between the continuous phases and the dispersed core material does polymerization take place.

A prepolymer with a low molecular weight is produced during the polymerization of the chemicals present there. Growing in size, this prepolymer deposits onto the surface of the dispersed core material to be encapsulated, where it continues further polymerization and crosslinking to form a solid capsule shell.[57]

Process of Emulsion Hardening

It is possible to produce emulsion hardening mircoencapsulation techniques when the core component dissolves readily in the polymer solution (wall). Following the emulsification of the combination in an immiscible liquid, the solvent is eliminated by evaporation, extraction, etc. The microcapsule is formed when the core chemical solidifies inside the droplet of polymer solution. The creation of poly(lactic) acid microcapsules for injectable particle systems is a usual example of this method. [57]

Spray-drying

When an active ingredient dissolves or suspends in a melt or polymer solution and is trapped in the dried particle, spray-drying functions as a microencapsulation process. The commonly used spray drying method creates the dried solid by finely dispersing an aqueous solution of the film-forming wall components and the core material into hot air. After the water evaporates, air separation is often used to separate the dry solid. Because of the short contact time in the drier, this technique has been utilized to encapsulate labile materials. The loss of some aromatics with low boiling points during the drying process is a drawback of the spray drying technique. An further drawback is that the core material could also form on the capsule's outside, allowing for oxidation and potential fragrance alterations of the substance that is within.[57]

Mechanism of release

The polymeric wall's structure determines how the components in the capsule will escape. The polymeric walls' density, permeability, and biological characteristics all have an important effect in how quickly materials are released. An other significant affecting component is the external environment. The core substances are generally

released from the capsules via four mechanisms:[55]

- -**Mechanical stimuli:** Applying pressure force and friction operation causes the wall of the capsules to physically and mechanically break down, allowing the core substance to be released gradually.
- **Chemical stimuli**: A variety of chemical processing techniques, including dissolving in an appropriate solvent, enzymatic activity, and altering environmental parameters like pH and temperature, may release core material from capsules.
- **Thermal stimuli:** At a temperature below the wall's melting point, the core material is contained in the capsule wall. The prepared capsules' core substance is destroyed and released when they are heated above the point at which the wall melts.
- **Diffusion:** The release of core material occurs when an external liquid, such water, diffuses into the capsule wall. It regulates the release by influencing the external liquid's permeability and solubility inside the wall matrix. The main factor controlling diffusion is the vapor pressure on each side of the capsule wall. Core material splits between the wall and the diffused liquid and travels out of the capsules' wall as the external liquid diffuses to the wall's surface. [55]

Applications of capsulation treatment in antimicrobial finishing of textiles

The Coleus ambonicus extract

Using exhaust, microencapsulation, and nanoencapsulation techniques, an extract from the Coleus ambonicus was applied to cotton fabric. The antimicrobial activity of the resulting fabric was assessed quantitatively using the AATCC test method 100 against both gram positive (Staphylococcus aureus) and gram negative (Escherichia coli) microbes. The samples that were finished utilizing all three procedures show a substantial percentage of bacterial decrease. Even after washing, the finish that was applied to the samples utilizing all three techniques had a greater percentage of bacterial decrease against gram positive microorganisms than gram negative. The proportion of germs that decreased after washing served as a test for the antimicrobial activity's wash durability. After ten wash cycles, the samples that were cleaned using the direct exhaust approach lost their antibacterial activity due to their extremely low wash durability. The microencapsulated technique samples exhibit antibacterial activity up to 10 wash cycles, however after 20 wash cycles, the activity steadily decreases to extremely low levels. Even after 30 washes, the wash durability of the nano encapsulated samples shows strong antibacterial activity against both gram-positive and gram-negative bacteria. [58]

Herbal extracts on denim fabric

Utilizing three plant extracts-Ricinus communis, Senna auriculata, and Euphorbia hirta to apply micro-encapsulation and nano-encapsulation to 100% cotton denim fabric, imparting their antimicrobial efficacy by finishing the methanol extracts of these herbs on the denim fabric. The most effective results in terms of antimicrobial efficiency are obtained when the herbal extract mix of Ricinus communis + Senna auriculata + Euphorbia hirta (1:3:2) is applied directly to denim using the exhaustion method in the conditions specified by AATCC 147 (20 kgf/cm^2 pressure and 20 m/min rpm speed). Herbal extracts are encapsulated and nano-encapsulated to increase the finished fabric's durability. The results demonstrate good microbial resistance against the test bacterial strains, even after 30 industrial washes. [59]

Eco-friendly antimicrobials on cotton fabric

A new attempt to combine the beneficial properties of controlled release microcapsules with environmentally friendly antimicrobials on cotton fabrics. For cotton textile materials, an environmentally friendly herbal anti-microbial finish has been created. Both the microcapsule finish application method and the direct pad-dry-cure approach have been used to apply extracts. The microcapsule finish application technique has been used to apply extracts. Neem, prickly chaff flower, aloe vera, and Mexican daisy extracts were used to create microcapsules, with alginate and gelatin functioning as the wall and core materials, respectively. The investigation revealed that the antibacterial activity of the microencapsulated finish application lasted for a higher number of washes. In terms of preventing the growth of bacteria, neem outperformed the other plants that were evaluated. [60]

Biogenic gold nanoparticles

The production of biogenic gold nanoparticles on cotton fabric (AuNPs-CC) was made simple and eco- friendly. It was discovered that the Au ions were gradually converted to nanoparticles by the hydroxyl functional groups of the cellulose macromolecules, which can be found in cotton. The kinetic process of AuNP production was sped up by using a concentration of citrus limon juice. Energy-dispersive spectroscopy (EDS), a field emission scanning electron microscope (FESEM), and other spectroscopic techniques were used to analyze the materials. The 22 nm size AuNPs bonded to the cotton fibers were clearly visible in the FESEM pictures. Using several strains, the antibacterial

activities of AuNPs were investigated. Pathogenic bacteria are susceptible to the antibacterial properties of Citrus Limon-assisted Synthesized AuNP. [61-64]

Zinc oxide nanoparticles

Research has been done on the use of zinc oxide nanoparticles in the fabrication of antimicrobial cotton textiles. Using the pad-dry-cure technique, ZnO nanoparticles were directly placed to 100% cotton woven fabric after being created by a wet chemical process. The agar diffusion and parallel streak methods were used to assess the antibacterial activity of the finished textiles, and the percentage reduction test was used to measure it. The treated and untreated fabrics' topographical analyses were examined and contrasted. Both qualitative and quantitative testing reveal that the completed cloth had strong antimicrobial activity against S. aureus. ZnO nanoparticles were embedded in the treated textiles, as shown by the SEM study. The treated cloth was proven to withstand up to 25 wash cycles in research on wash durability. [5, 16, 22, 65-68]

Aloe Vera extraction

To create antimicrobial cloth, aloe gel has been added to 100% cotton fabric. Cotton fabric was treated with aloe vera extract at different concentrations—1, 2, 3, and 5 gpl—at 60°C for 30 minutes using the pad-dry-cure method to optimize the process parameter. The Aloe vera plant's aloe gel was extracted using methanol as a solvent. The finished fabric samples got activity testing using the quantitative analytical test technique and the ATCC (Agar diffusion) method. Staphylococcus aureus (ATCC 6538) was susceptible to the antibacterial action of textiles treated with aloe gel. At a concentration of 5 gpl, the treated cotton textiles exhibited excellent antibacterial activity. Even after 50 washes, it was discovered that the treated sample had good wash durability. [69-71]

CuO nanoparticles

By using ultrasonic irradiation, copper oxide nanoparticles were created and then applied to the cotton fiber surface. X-ray diffraction and scanning electron microscopy/energy dispersive X-ray analysis were used to analyze the structure and morphology of the coated and uncoated cottons. These techniques demonstrated the crystalline nature of CuO nanoparticles and their physical adsorption onto the cotton fiber surface. The treated cotton fibers have distinct physical and chemical characteristics from the untreated cotton fibers, with an average crystallite size of 10 nm. When tested against Gram-negative and Gram-positive cultures of Escherichia coli and Staphylococcus aureus, the CuO cotton fiber nanocomposites demonstrated strong antimicrobial activity; in contrast, the analogous CuS-coated cotton material, which was created by reacting CuO-coated cotton fibers with H2S, exhibited no activity.[72-76]

Natural encapsulation

to investigate the antibacterial properties of neem, tulsi, and turmeric-encapsulated microcapsules and their use on cellulosic fabric.

Using a natural encapsulation approach including yeast, the simple diffusion method was used to form the herb combination into microcapsules, which were then applied to cotton and silk fabrics using the pad-dry-cure method. At 120 °C, the microcapsules were attached to cotton and silk fabrics using a binder. Staphylococcus aureus, Escherichia coli, and pseudomonas were three types of bacteria used to assess the antibacterial activity of the finished fabric.

The prepared microcapsule demonstrated excellent antimicrobial activity against Pseudomonas, and the results of tests including the parallel streak method and disc diffusion method demonstrated that the mixture of herbs had very effective antimicrobial activity against the three types of bacteria that were chosen.[77]

Conclusion

Antimicrobial preparation is an important process because fabric is a suitable environment for the growth and reproduction of bacteria due to humidity. Therefore, these microbes present in clothing may cause diseases in humans when they come into contact with the skin. Therefore, the antimicrobial preparation process must be performed. There are many techniques that can be used in this preparation using different materials. Supercritical can be used in this preparation, thereby saving water and energy consumption. This method is used with different materials such as chitin and chitosan. Plasma of various types can also be used to increase the ability of the material to resist microbes by increasing the loading of processing materials on the surface of the material. Encapsulation technology, whether nano or micro, is used by extracting herbal plants and using them in the capsule, which are released gradually in order to obtain an antimicrobial preparation.

Conflict of Interest

There is no conflict of interest in the publication of this article.

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