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Microencapsulation and its Application in Textile Industry

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Abstract

The provided text selection discusses the development and use of microencapsulation in the textile industry. It explains how microencapsulation involves the creation of tiny structures called microcapsules that contain bioactive compounds or polymers, and these capsules can protect the encapsulated substances from various environmental factors. The text also describes different methods used to produce microcapsules, such as chemical, physical-chemical, and physical methods. It further explores the applications of microcapsules in textile functionalization, including antimicrobial finishing, aroma finishing, phase change materials finishing, mosquito repellent finishing, self-cleaning and water repellent finishing, and flame retardant finishing. The processes and techniques used in each application are detailed, providing insights into the fabrication and benefits of microencapsulation in textile processing.

Keywords:(textile – finishing – Microencapsulation – techniques)

Introduction

Many new, greener, and cleaner technologies have been developed in response to environmental demands and concerns, as well as crises for environmentally friendly textile processing. This is especially true in the wake of research laboratories and textile manufacturers working together to develop a range of eco-friendly textile finishes. Science has created a wide range of environmentally friendly textile processing techniques, such as microencapsulation, plasma technology, enzymatic textile finishing, and natural product finishing. [1-9]

Microencapsulation has emerged as a challenging approach for creating innovative biotechnological materials. The formation of tiny "packaging" known as microparticles, microspheres, or microcapsules—which are composed of structures that contain one or more bioactive compounds or are immobilized by one or more polymers—is referred to as microencapsulation.

Microencapsulation is the process of encasing liquid droplets, solid particles, or gas molecules in an encapsulating agent, matrix, or wall material. To create microscopic capsules with a range of properties, these compounds are either fully encapsulated in a covering material or incorporated into a homogeneous or heterogeneous matrix. There are two parts to the microcapsules: the wall/shell and the center. Active compounds can be shielded by the microencapsulation process from potentially hazardous environments including heat, oxidation, acidity, alkalinity, moisture, or evaporation. [10, 11]

Encapsulation

The two components of a microcapsule are the shell and the core. An active material, such as a hardener, is present in the core (intrinsic component), whereas the shell (extrinsic element) either temporarily or permanently isolates the core from the outside world. [5, 12-16]

Categorization

Microcapsules can be categorized according to their morphology or size.

A. Nano/microcapsules

The size of a microcapsule can vary from a few millimeters to a thousandth of a millimeter. To highlight their minuscule size, microcapsules with a

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diameter in the nanometer range are called nanocapsules.

B. Microcapsules of morphology

Three fundamental categories can be used to categorize microcapsules, as listed below:

a) A. mononuclear microcapsule: consists of a single hollow chamber.
b) b. Polynuclear microcapsules: the shell of these particles contains many chambers of varying sizes.
c) c. Matrix type microparticle: The matrix of the shell material contains the embedded active compounds. Nonetheless, the selection of shell materials and microencapsulation techniques largely dictate the internal structure of a microparticle.[17]

Methods to produce nanocapsules and an explanation of their essential mechanisms

Chemical methods

Polymerization

a) An emulsion's monomers polymerize around the droplets to form an extremely durable polymeric wall.
b) On-site polymerization Monomers or pre-condensates are only given to the emulsion's aqueous phase.
c) Polymerization at the boundary Whereas the other monomer dissolves in a lypophilic solvent, the first monomer dissolves in water.[18]

Physicochemical methods

Coacervation

Scattered microcapsule cores are encased in a viscous microcapsule wall created by the macromolecular colloid-rich coacervate droplets, which is then strengthened by cross-linking agents. This phenomenon can be found in systems with colloid particles.[19]

Simple coacervation

The phases in simple coacervation are separated using a disolvation agent.

a) **Complex coacervation**: This is the phase separation of a liquid precipitate or phase that occurs when solutions of two hydrophilic colloids are mixed under the right conditions. The solvent evaporates, forming the three phases of the solution and leaving the sheath over the core substance.[18]

Physical methods

a) Spray drying: This process creates capsules by spraying an emulsion of shell and core material into a heating chamber with precisely calibrated atomization. The solvent soon evaporates in the chamber. The following are the stages involved in the microencapsulation process:
    - spraying the emulsion steadily and minutely into droplets using an atomizer.
    - Drying the previously dispersed droplets with hot gas.
    - Gathering and sorting the capsules with cyclones and filters.[20]
b) b. Pan Coating: After inserting the core particle into the pan, the polymer is gradually injected into the pan, causing it to rotate more slowly and completely coat the core material.[21]
c) c. Air suspension coating: This involves spraying a coating over the air suspended particles after the core material has been dispersed in a supporting air stream.[22]
d) d. Centrifugal extrusion: This method employs nozzle heads for both the core and shell components in a concentric feed system. Microcapsules are produced as a result of vibration, curing activity, and the insertion of a melt or solution polymer into the nozzle shell after the liquid active core is deposited in the nozzle's center.[23]
e) e. Solvent evaporation method: In the dissolved polymer volatile solution, the active main constituent dissolves gradually. The microcapsule is removed from the solution as the solvent evaporates.[21]

Techniques for Using Microcapsules on Textiles

At several stages of the fabric development process, from the polymer to the fabric stage, microcapsules can be mechanically incorporated.

- In the polymer (microcapsules are injected into the fibers during the spinning process).
- The method of immersion, Unlike with the padding method, the cloth is not run through the squeezing rollers.
- The padding process involves pushing the material through cushioning rollers to eliminate any extra liquid once it has been delivered by microcapsule dispersion.
- The printing process uses screen, photographic, electrostatic, pressure-transfer, thermal transfer, and inkjet printing techniques. Microcapsules and a binder are combined to make the printing paste, which is then applied to the fabric.
- Using the coating procedure, a uniform coating of microcapsules is applied to the materials.

- In the spraying approach, a spray nozzle is used to spray the microcapsules onto the fabric within a closed chamber. The microcapsules are then stabilized on the fabric by heat treatment at a high temperature (130–170 C).[20, 24]

Release Mechanism

Such effects in permeability and non-permeable microcapsules have been reported to be achieved by eight different release mechanisms.

a) **External pressure**: This procedure results in the mechanical breaking of the microcapsules.

b) **Internal pressure**: could perhaps lead to the microcapsule wall breaking, for instance, if the core-shell contains substances that, when exposed to specific stimuli (such as radiation), change into gaseous products, as is the case when light synthetic leather is made.

c) **Microcapsule wall abrasion**: This technique is frequently used when releasing a smell.

d) Burning: Fire retardants are released when a temperature reaches a particular point.

e) **Radiation**: The release of microencapsulated dyes from this approach might cause photographic and light-sensitive processes to be triggered, changing the color of these materials.

f) **Temperature Variations**: Core material release can be facilitated by temperature changes. There are two distinct release processes:
   - Temperature-sensitive: The wall expands and descends when the critical temperature is achieved.
   - Fusion-activated: As the temperature rises, the wall dissolves.

g) **Chemical reactions**: This is the case when textile washing or cleaning formulations incorporate microcapsules containing chemicals that are released throughout the wash cycle as a result of changes in pH or chemical composition.

h) **Enzymatic degradation**: Under certain conditions, enzymes break down microcapsules. [25]

Functionalizing of fabric

Antimicrobial Finishing

The use of encapsulated essential oils in chemical finishing for textiles is expanding quickly due to their adaptability and flexibility. In this study, alginate nanocapsules containing peppermint oil were created using the microemulsion technique and then microwave-cured onto cotton fabric. A good antibacterial and aromatic textile was obtained by optimizing effective factors on the antimicrobial activity of final cotton fabric. The amount of nanocapsules on the cotton fabric was measured using TGA and FT-IR spectroscopy. SEM pictures were also used to examine the nanocapsules' preferred location, attendance, and surface distribution on the textile fibers. According to GC-MS examination of the peppermint oil releasing behavior from the completed cotton fabric in various washing cycles, the percentage of peppermint oil reached 16 percent after 25 washing cycles. Under ideal circumstances, the completed fabric's antimicrobial activity demonstrated a 100% bacterial decrease for both S. aureus and E. coli. [2, 26-31]

The antimicrobial activity of the finished fabric was quantitatively evaluated using the AATCC test method 100 against gram positive (Staphylococcus aureus) and gram negative (Escherichia coli) microbes. An extract derived from Coleus ambonicus was applied to cotton fabric using the exhaust, micro encapsulation, and nano encapsulation methods. A good percentage of bacterial decrease is shown in the finish applied to the samples utilizing all three procedures. Even after being washed, the finish applied to the samples using all three techniques has a larger bacterial reduction % against gram positive germs than gram negative.[32]

Aroma finishing

Textile chemists have long wished to develop a long-lasting fragrance finish on textiles. Fragrances are volatile, but because capsules significantly slow down the pace at which aroma evaporation occurs, scents that are microencapsulated can remain on fabrics for extended periods of time. A cloth with an aroma finish needs to be machine washable. As a result, fragrance capsules finished on fabrics ought to endure hard washing conditions in addition to a lengthy shelf life. The fabric must undergo a curing treatment in order for the fixing agent to bond with the capsules because there is little affinity between the encapsulated scent and the fabric. On the other hand, the curing process is often a high-temperature heat process that quickly evaporates the scent from the capsules. As a result, the aromatic durability of textiles might fluctuate greatly depending on the fixing chemicals and curing techniques used. Three types of curing conditions, three types of fixing agents, and three types of thermal curing equipment were examined. A washing durable aroma capsule finishing procedure for cotton fabric was created by analyzing the properties of the fixing agents, the curing apparatus's heat transfer characteristics, and the provided energies during the curing conditions.[33]

Lemongrass oil was applied to fabric in this investigation using two different techniques: the exhaust method and oil microcapsules delivered through padding. The complicated coacervation procedure was used to create the lemongrass oil microcapsules, which were then applied to the cloth using the pad dry cure technique. The samples handled with both methods had their scent retention evaluated both before and after washing, and the method that produced the best results was put through additional testing, such as SEM analysis and antibacterial activity. Using AATCC-100, the antimicrobial evaluation of the treated and control fabrics was carried out. The outcomes showed that garments treated with exhaust technique were less successful in retaining scent than fabrics treated with lemongrass oil microcapsules. The fabric treated with lemongrass oil microcapsules exhibited an 80% reduction in microorganisms. The microcapsules were spherical in shape, and SEM micrographs showed that the fabrics could hold onto the microcapsules for up to 30 washes. [34]

Phase change materials finishing

Thermal management solutions have traditionally been challenged by the high temperatures and large amounts of heat seen in steel, sports, and glass manufacturing. Researchers are always trying to solve this difficult issue by developing intelligent smart textiles. By releasing the heat energy, they have received in a cold environment and storing heat in a hot environment, PCMs are able to sense environmental cues. Since PCMs undergo phase changes throughout the melting and crystallization processes from liquid to solid and vice versa they cannot be incorporated or applied to textiles without encapsulation. PCMs should be microencapsulated or nanoencapsulated for improved applicability and durability in order to solve the leakage issue. Microencapsulation is the process of wrapping or encasing the active or core material such as PCM into a protective capsule. [35-45]

Mosquito repellent finishing

The results of this investigation indicate that both knitted samples containing nanocapsules exhibited antimalarial activity. As anticipated, it was discovered that, in comparison to silica nanocapsules integrating permethrin, the technical solution developed based on silica nanocapsules combining natural essential oil Schinus molle is more environmentally friendly and yields better antimalarial efficacy outcomes. Regarding the tests that were conducted later, the sample demonstrated satisfactory behavior in every property that was assessed. The research concludes that the 100% PLA knitted structure with encapsulated natural essential oil combines the optimum attributes for the construction of biodegradable antimalarial clothing, based on a comprehensive global analysis of all the properties assessed. An application for a national patent has already been submitted as a result of this research.[4, 7, 9, 13, 46-49]

Self-Cleaning and water repellent finishing

As more research is done on how smart and functional textiles might be used in other industries, this interest in these materials is growing. This study presents the use of perfluorooctyltriethoxysilane (FAS13)-loaded silica nanocapsules as the Pickering emulsifier to stabilize O/W emulsion and produce pH-responsive dual-compartmental microcapsules with a strawberry-like structure. The shell of the microcapsules is composed of pH-responsive polymers and jasmine essence. By functionalizing the fabric, these microcapsules might give it multiple uses, and the preparation and functionalization processes are simple and safe for the environment. Due to the hydrophobic FAS13 being loaded into silica nanocapsules and the surface modification of UV absorbent, the treated fabric not only exhibits self-healing superhydrophobicity and UV resistance, but it also has the ability to control pH and release jasmine essence, which preserves over 40% of the fragrance for three months through the microcapsules' controlled release.[29, 47, 50-56]

Flame retardant finishing

High flame retardance of polymer materials requires a significant amount of flame retardant, yet this results in noticeably reduced physical qualities. In the meantime, there has been a significant need for halogen-free flame retardants that prevent the production of harmful fumes during combustion. However, there isn't currently a halogen-free flame retardant that performs as well as halogen flame retardants. Here, we suggest one promising way to produce a strong flame retardant impact with a small amount of a traditional flame retardant: the halogen free flame retardant's nanoencapsulation technology. We used a co-milling technique as a nanoencapsulation technology and were successful in creating a multilayer compound with the halogen-free flame retardant inside of it. We discovered that the exdoliated and intercalated states of the nanocapsules are co-mixed in the resin. Despite the nanocapsule containing a modest amount of flame retardant, the results indicate that the manufactured nanocapsule has a good flame-retardant function. Additionally, by mixing the commercially available flame retardant with the nanocapsule, the synergy effect for the enhanced flame retardance has been examined. After using extremely flammable crosslinked foam to reinforce the synergy effect, the material was categorized as UL VO. [57-60]

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Conflict of Interest

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

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