Innovations

Microencapsulation Utilizing Polymer and Biopolymer Systems Represents an Expanding Domain Characterized by Numerous Contemporary Trends and Prospective Applications

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Abstract: *Phase change material (PCM) microencapsulation is useful for increasing PCMs' thermal conductivity and guarding against potential environmental interactions and leakage during the melting process. However, there isn't a comprehensive guide to all the different ways that PCMs can be microencapsulated, as this can result in microcapsules with varying morphology, structure, and thermal properties.The three categories of microencapsulation methods—physical, physic-chemical, and chemical processesare examined and categorized in this research. It is a helpful resource for researchers in this field, asit provides an overview of the methods used for PCM microencapsulation. This method has been applied in various industries, including printing, culinary, textile, pharmaceutical, and defense. This approach has brought self-healing composites and chemically decontaminating materials to the defense academy.This review article discusses materials used in microencapsulation, microencapsulation technologies, microencapsulation goals, microencapsulation morphology and methodology of microcapsules, the release mechanism, and the fields in which microencapsulated additives are used in building materials.*

Keywords: *Microsphere, Pan coating, Air-suspension, Ionic gelation, and defence academy.*

Introduction:

The pharmaceutical industry uses a method called microcapsule, which is developing quickly. It is a method for coating minuscule solid particles with a relatively thin layer to create liquid droplets and dispersions. The way that microencapsulation differs from

large-scale approaches is that the former entails encapsulating substances that are rapidly utilized by the human body and that also have unique medicinal effects. It has become evident that our notion provides a new working tool for the industrial pharmacist as technology advances. Microencapsulation finds application in both the pharmaceutical and food industries. [1]

The technique was created in the late 1930s to offer a more environmentally friendly substitute for the carbon paper and carbon ribbons that the business machine industry needs. Reproduction paper and dye-containing ribbons were eventually produced in the 1950s, albeit their impact was minimal because they released gelatine capsules when they struck objects. Under the pressure of a pen or pencil, a teletype was essential in promoting the creation of numerous microencapsulated materials, including pharmaceuticals. [2]

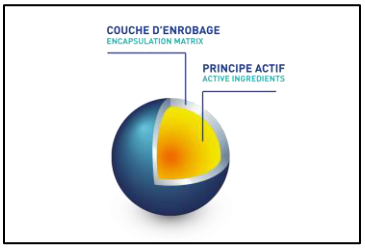

Fig.1 Microencapsulation

Motiveof microencapsulation:

The usage of microencapsulation has numerous benefits.Isolating the core from its surrounds is necessary in some instances, such as preventing oxygen from destroying vitamins, postponing the evaporation of volatile cores, improving the handling properties of sticky substances, or defending reactive cores from chemical attacks. Instead of completely isolating the core, the objective in other scenarioslike the rational release of drugs or pesticides—is to standardize the rate at which the core emerges from the microcapsule. The problem may be as simple as lessening the flavor or odor of the core, or it could be more complex like increasing the selectivity of an adsorption or extraction process. [3]

Fundamental consideration:

Understanding the fundamentals of microcapsules, such as the makeup of the coating and core materials, the stability and release characteristics of the coated materials, and the microencapsulation procedures, is necessary to fully realize the potential of microencapsulation.[4]

1. **Microencapsulation Techniques:** -The following are the classes of approaches for microencapsulation: Chemical, physical, and physical-chemical techniques include in-situ polymerization and liposome synthesis; physical techniques include spray-

drying and fluidized beds. Two coating and physicochemical techniques include coacervation and sol-gel encapsulation.[1]

2. **Classification of Microcapsules:** - Microspheres or microcapsules are the names given tospherical microparticles! These tiny spheres are called microspheres or microcapsules. There is a thin coating covering this little sphere. The composition of the coating and the core components can affect the shape of microspheres or microcapsules.[5]Microspheres or microcapsules are the names given to spherical microparticlesThese tiny spheres are called microspheres or microcapsules. There is a thin coating covering this little sphere. The composition of the coating and the core components can affect the shape of microspheres or microcapsules.[5]

(a) Mononuclear (core-shell) microcapsules: - These microcapsules have one care in the shell.

b) polynuclear microcapsules: "These microcapsules have many cores within the shell.

c) Matrix on capsulation: The ideal Process for encapsulating substances such as oil or active components in a suitable material. In this process, it is based on fluidized bed technology.[6]

3. Formulation of Microspheres: -

Microspheres consist of two components -

3.1) Core material: -The term "core material" refers to the substance that is coated and may or may not be solid or liquid. The main constituents consist of stabilizers, diluents, excipients, and active substances.

3.2) Coating material: -The substance that is applied as a coating or shell during microencapsulation. The goal of coat materials is to coat the core material.

The choice of coating material is determined by the physical and property properties of the resulting microcapsules on microspheres. Stability, tastelessness, and optical characteristics are attributes of coating materials.[10]

Properties of Coating Material: -

a) Coating material should stabilize the core material.

b) The typical coating properties are moisture, sorption, and solubility.

c) This coating can be flexible, thin, or a little hard.

d) It is tasteless and stable.

e) These are non-hygroscopic, non-high, viscous, and economical.

Composition of coating material:

The composition of the coating material

a) polymer

b) Plasticizer and

C) coloring agent

Advantages:

a) Better control of drug absorption and good bioavailability.
b) They protect encapsulated enzymes from low pH.
c) Protect reactive substances from the environment.
d) Can minimize the toxicity and side effects. And maximum therapeutic efficacy.
e) It prevents GIT from the irritant effect of the drug.[5]

Disadvantage:

a) Cross reaction between core and wall material.
b) Hard to achieve rapid and uniform film.
c) The shelf life of hygroscopic drugs is decreased.
d) It is very costly.
e) More skills and knowledge are mandatory.

Preparation or Methodology:

Coacervation, sol-gel encapsulation, spray drying, and fluidized bed coating are examples of microencapsulation techniques used in pharmaceuticals. Techniques like polymerization and vacuum deposition are not now used in pharmaceutical preparation.[7]

Spray drying: In this method, the drug is dissolved in the polymer solution. In the spray drying process, core material is mixed in a solution of shell material, then forms a stable emulsion.There are several use cases of spray dryingtechniques related to the food and pharmaceutical industries because of more advantages including those of low cost, easy transformation to the industrial scale, and high drug loading efficiency.[8] Depending on the beginnings of feed material and operating conditions, spray–drying produces either large-size particles of 2-3 mm or a very fine powder of 10-50 mm. When an active material breaks down or stops in meet or polymer solution and becomes encapsulated in the dried particle, spray drying functions as a microencapsulation technique. Still, many kinds of different encapsulating materials may be used melting point of (45–122) °C has been recorded for fat and stearin, while (45-65)°Cis recorded for mono and diacylglycerols. Usually, fractional or hydrogenated vegetable oil with a melting point between 32°C and 42°C is used as the substance used for coating in spray-chilling.[3]

These techniques work by drying the drug and polymer spray that is in the air. Spray drying and spray congealing are two procedures that involve either the removal of the solvent or the cooling of the solution.[15]Spray drying and spray clotting are similar processes that entail dispersing the core material into a fluidized coating material and spraying or suggesting the core coating mixture into the surrounding conditions, resulting in a relatively constant solidification of the coating. Among the benefits of this technique is that it can be freely customized and applied to a wide range of materials and encapsulating agents.[7]

Application:

- Spray dryers are used for the drying of liquid materials like emulsion, suspension, solution, slurries, thin pastes, etc.
- Spray drying can be used to dry materials that are sensitive to heat or oxidation without degrading them, even when high-temperature air is employed.
- Droplets of the liquid feed are distributed, and because of their large surface area and proximity to the drying gas, they dry in a matter of seconds.
- The product is kept cool by the vaporization of the enveloping liquid, and the dried product is kept from overheating by rapid removal from the drying zone.
- The improvement in flow and reduction of air entrapment makes the spray-dried material suitable for use in the manufacturing of tablets and capsules.[9]

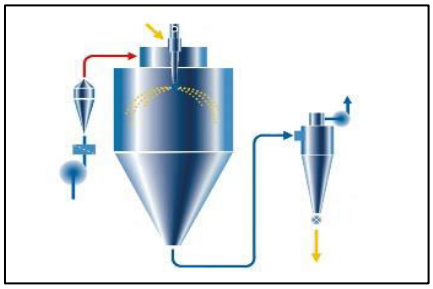

Fig.2 Spray drying

Ionic Gelation Method: A homogenous polymer mixture is created by dispersing the polymeric system in purified water. The drug is fully combined with the polymeric matrix to create a smooth, viscous dispersion. The resulting dispersion is then continuously stirred while being added drop by drop to a solution of bivalent or trivalent salts (calcium chloride, aluminum chloride).[4]The generated droplets are kept in the divalent/trivalent salt solution for a while to finish the curing process and form hard, spherical microspheres. The resulting microspheres are collected by decantation, and the product so separated is dried by the required requirements after being repeatedly washed with purified water to eliminate excess calcium impurity that has developed on the surface of microspheres.[10,11]

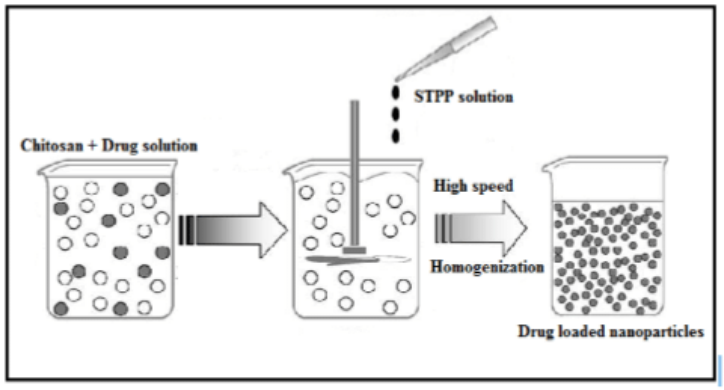

Fig.3 Ionic gelation method

Application:

Air Suspension Method: Professor Dale E. Wurster invented this procedure. Using the air suspension technique, the coated materialsare sprayed onto the air-suspended particles after the core materials have been distributed in a supporting air stream. Within the coating chamber, the particles are suspended upward by the removing air stream. This is a multi-cycle procedure that is repeated. The coating material's concentration solubility, surface area, volatility of the core material, melting point, and application rate are all impacted by this procedure. Techniques involving air suspension can effectively encapsulate micron-sized particles.[10,12]

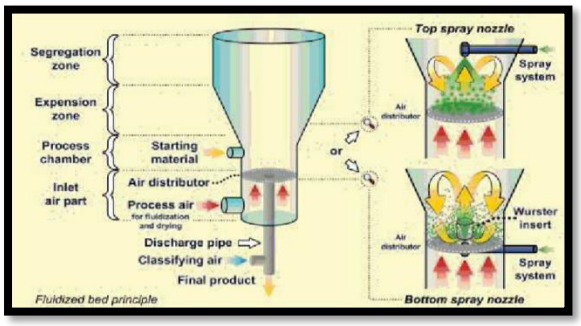

Fig. 4Air suspension method

Fluidized Bed Coating:

The particle is coated with the liquid coating, and as it continues to evaporate, the particle's outer layer forms. It is possible to get the desired coating formation and thickness. Three stages comprise the mechanism of microcapsule creation techniques: nucleation, transition, and ball growth. By shifting the nozzle's location, the fluidized-bed coating technique can be altered.[7]

The different fluidized–bed coating methods are

1] Top-spray

2] Bottom-spray

3] Tangential–spray.

This technique uses nutritional substances like vitamin C, B vit, ferrous sulfate, ferrous fumarate, and potassium chloride.[13]

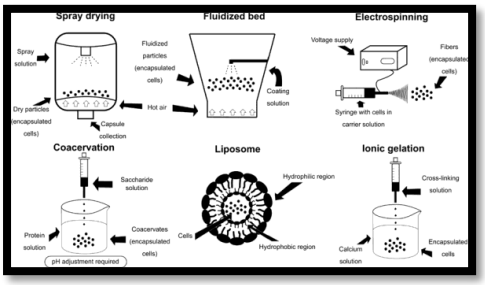

Fig. 5 Fluidized bed coating

Physicochemical Method

Coacervation Method: The first and most widely used encapsulating method is called coacervation.It involves the coacervation of formation existing within a small pH range and the electrostatic encapsulation attraction between two biopolymers of displeasure alterations.[6]Coacervation is a common process in which the core material is surrounded by a homologous layer of polymeric wall material. After being combined, the wall and core materials create an immiscible solution. There are two types of coacervation techniques: "simple" and "complex." On coating material, simple coacervation has been applied. The basic coacervation process is reliant on temperature, ionic strength, pH, and macromolecule structure.[9]The complicated coacervation process relies on both the polymer's conc and pH. This process involves the interaction of two polymers with opposing charges.We refer to this technique as the "polymer-polymer interaction method." Through electrostatic contact, negatively charged polysaccharides (like acacia and pectin) are sandwiched between positively charged proteins (like gelatin and soy protein isolate).[11]

The batch-type coacervation process has three types, they are -

1. Formation of three – immiscible chemical phases.
2. Deposition of the coating
3. Solidification of the coating

The disadvantage of this method: -

- The coacervation method is more expensive than the complex coacervation method.

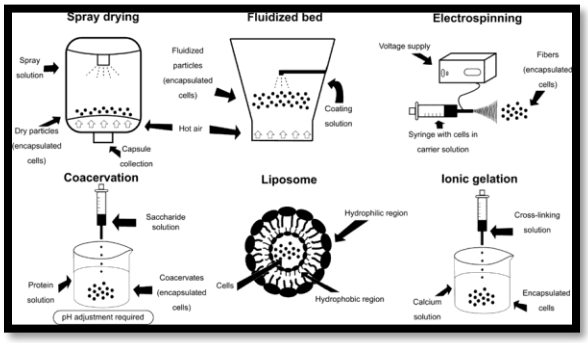

Fig. 6 Coacervation Method

Single Emulsion Method:

Natural Polymers using the single emulsion technique. Natural polymers are first dissolved in an aqueous medium and subsequently dispersed in a non-aqueous liquid, such as oil. Proteins and carbohydrates are transformed into micro particulates.[6]The polymer solution, consisting of a volatile organic solvent such as dichloromethane that is immiscible in water, is suspended or dissolved by the medication. When the solvent in the emulsion is added in excess, either by evaporating at high temperatures or by utilizing a large amount of water, compact microparticles are created.[3]The pace at which the solvent is withdrawn from the mixture, the temperature of the medium, the solubility characteristics of the polymer, and the kind of solvent eliminated are all considered to have an impact on the final morphology of microparticles. [8]

Poor encapsulation efficiencies may arise from hydrophilic medicines' propensity to permeate from the dispersed oil phase into the aqueous phase. This technique is exclusive to hydrophobic medications.[10]

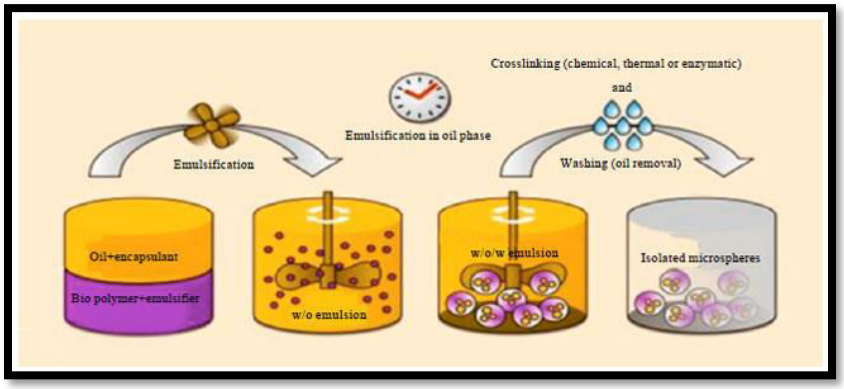

Fig. 7 Preparation of single emulsion method

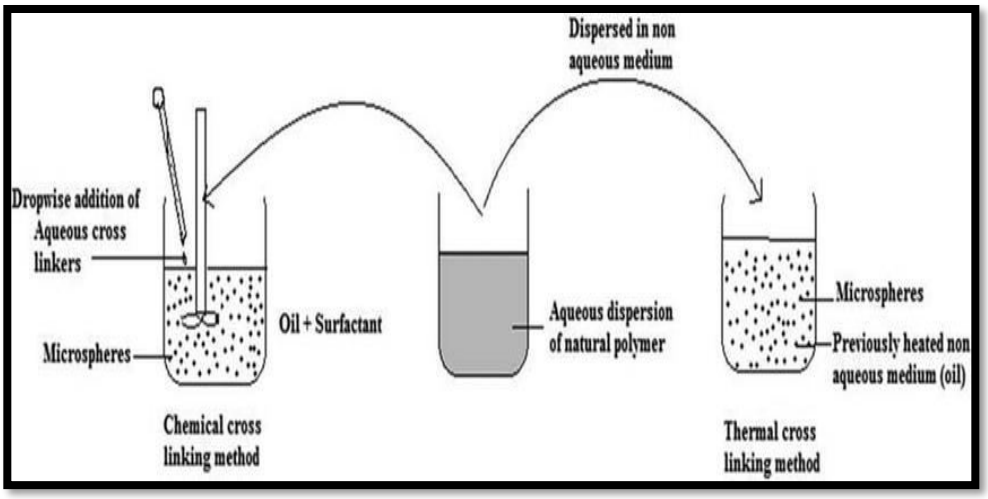

Fig. 8 Single Emulsion method

Double Emulsion Method:

Another name for it is primary emulsion. Since this method of preparation of microsphere produces multiple emulsionsof type w/o/w, such as proteins, peptides, and vaccines, it is most effective when used with water-soluble medication.[15]This main emulsion is vigorously stirred into an excess of water containing an emulsifier to produce the final w/o/w emulsion. The following stage involves an extraction or evaporation process to remove the solvent. One advantage of this strategy is that hydrophilic medications can be efficiently encapsulated in an aqueous phase.[1]

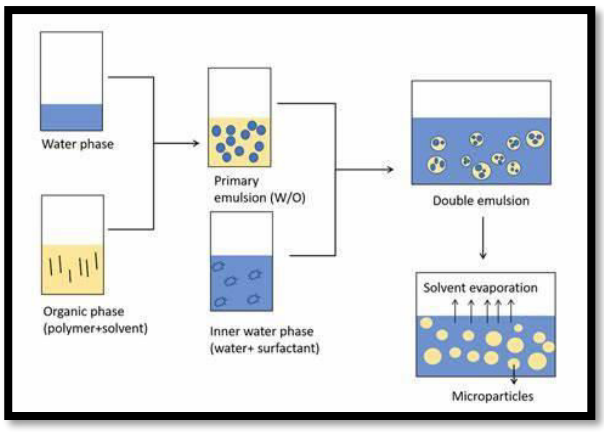

Fig. 9 Preparation of Double emulsion method

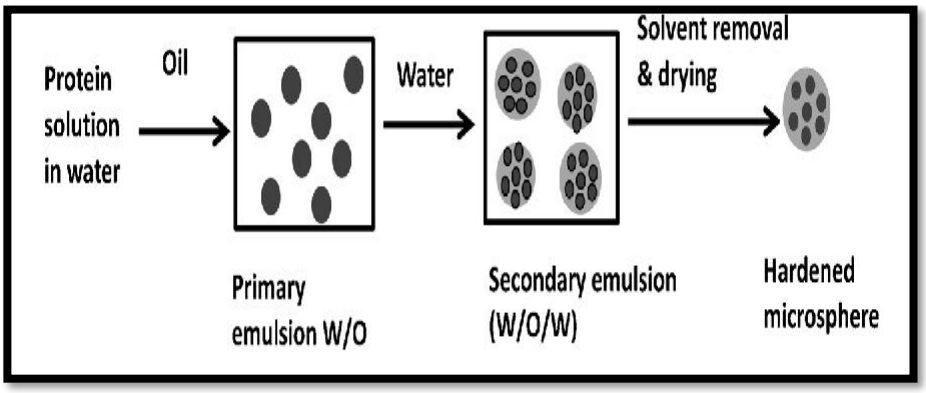

Fig. 10 Double Emulsion method

Pan coating method:

The pan-coating method is one of the oldest industrial procedures for producing small, coated particles or tablets, and it was widely used in the pharmaceutical industry.The particles are dropped into a pan or equivalent device, and the coating material is applied gradually. [2,14]The coating material is applied gradually when the particles fall into a pan. Larger solid particles above 600 μm are typically considered essential for effective coating in terms of microencapsulation. When the coating is applied, it is sprayed

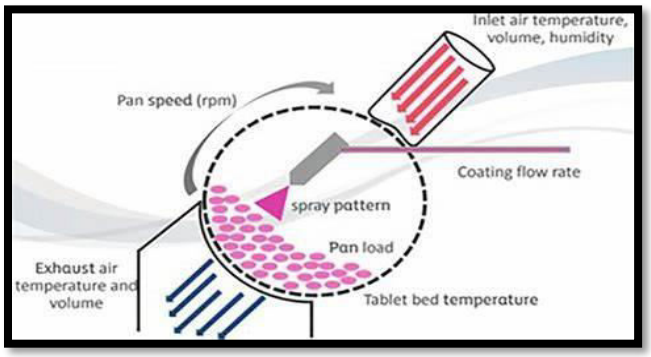

Fig. 11 Pan coating method

as an atomized spray or as a solution onto the intended solid core material. To remove the coating solvent, warm air is usually circulated over the coated items in the coating pans as the coating is being applied.[6]

Mechanism and kinetics of drug release:

The four main processes by which drugs are released from microcapsules are osmosis, erosion, dissolution, and diffusion.[9,15]

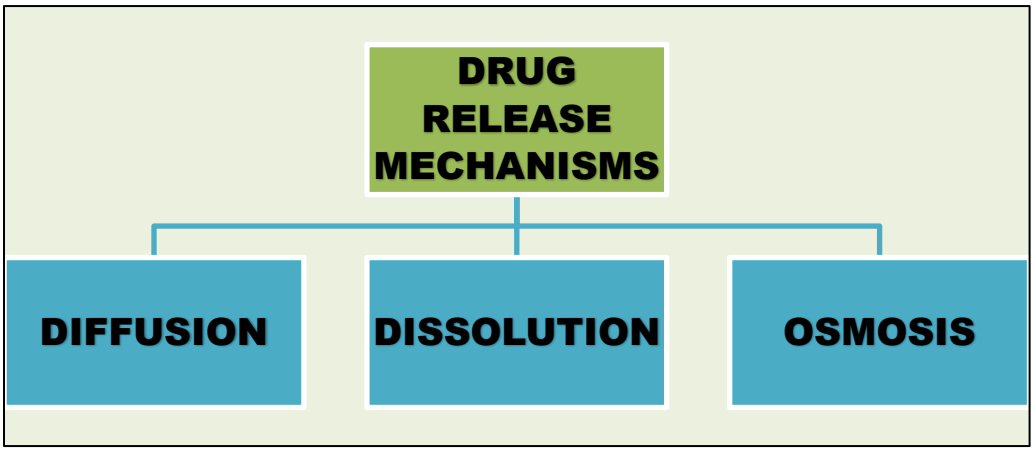

Fig. 12Drug release mechanisms

Diffusion:

Drug release through core material is most commonly achieved by dissolving a fluid that enters the shell, meets the core material, and then leaks out through pores or interstitial spaces. The consequences of drug release include how quickly the drug dissolves in the dissolution fluid, how quickly the dissolution fluid enters the microcapsules, and how quickly the dissolved drug departs from the microcapsule. Higuchi's equation can be used to calculate such drug release kinetics: Q = [D/J (2A-ε CS) CS t] ½, where A is the total amount of drug per unit volume, ε is the porosity of the microcapsule wall, CS is the drug's solubility in permeating dissolution fluid, J is the tortuosity of the capillary system in the wall, D is the solute's diffusion coefficient in the solution, and Q is the amount of drug released per unit area of exposed surface in time.[8,16,17]

Dissolution:

This rate determines how quickly the medicine is released from the microcapsule when the polymer covering dissolves in the dissolving fluid. The coating's thickness and solubility in the dissolving fluid have an impact on the release rate.[5,18,19,20]

Osmosis:

Another method of drug release is osmosis. Osmosis requires semipermeable membranes, which polymer coatings in microcapsules provide. Because the process generates an osmotic pressure between the interior and outside membranes, the medicine is released through microscopic pores in the microcapsule. Drug release occurs when some coat materials, like glyceryl monostearate, stearyl alcohol, and beeswax,

erode because of enzymatic hydrolysis or pH changes (Schacht and Van, 1987).[6]The release of pharmaceuticals from microcapsules has gotten more complex due to the considerable variety in the size, shape, and arrangement of the core and coat materials within them, as well as their physical shapes. It is difficult to estimate drug release because of the physicochemical properties of core materials (such as solubility, infusibility, and partition coefficient) and coating materials (such as thickness, inertness, and varying porosity).[4]However, based on several investigations of the release characteristics, the following aspects might be taken into consideration:

1. Drug release rates from microcapsules are controlled by zero-order kinetics. During the first half of the drug release, monolithic microcapsules show a t1/2-dependent release rate; this is followed by an exponential fall.
2. monolithic microcapsules containing an excess of the dissolved drug; for almost the complete drug release lifetime, the release rate is t1/2 dependent.
3. Because the medicine at the center of a monolithic capsule travels a greater distance than the drug at the surface, the drug's path differs. As such, the rate at which monolithic capsules are released usually diminishes with time.
4. Manufacturing microcapsules Important Ingredients: The core material's surface might be either liquid or solid. As a result, the release rate in monolithic capsules typically reduces the duration.[21,22]

Applications:

1) The microencapsulation process is fully utilized in the pharmaceutical business to disguise flavors, enhance stability, and regulate the release of drugs and food items such as juices, chocolate, meat, and poultry products.
2) It is used to cover up the taste of bitter medications, such as nitrofurantoin and paracetamol.
3) From a mechanical point of view, oily drugs have been included in the dosage of tablets using microencapsulation. This has been utilized to circumvent problems arising from the tableting of sticky granulations. Utilizing improved flow properties, this was accomplished. For example, the iron phosphate, thiamine hydrochloride, riboflavin, and niacin multicomponent solid mixture that is not flowable could be compressed and encapsulated directly into the tablets.
4) The key elements of the atmosphere's effects have been addressed through the use of microencapsulation.
5) A thorough understanding of the interactions between an encapsulated core material and the wall material, as well as how stability is maintained in various food ingredients utilized as an ingredient during food processing, is crucial.
6) Antimicrobial textiles are widely utilized in home textile items and personal care products. Nowadays, non-antimicrobial materials are used in the production of functional textiles.

7) It's employed in the making of beverages, shielding molecules from other substances, and inoculating soil.
8) Decomposition is a primary factor that shortens the shelf life of fruits and vegetables after harvest and results in large financial losses. Fungicides and insecticides are frequently used to reduce post-harvest losses and deterioration in crops.
9) Tropical parts are subjected to mosquito-borneillnesses such as filariasis, malaria, and dengue hemorrhagic fever. Citronella essential oil microcapsules applied topically as an ointment proved to be an effective mosquito repellent when utilized by Solomon. It was discovered that microencapsulation slowed down the oil's rate of evaporation and provided a viable way to increase citronella oil's potential mosquito–repelling range of action.

10) Microencapsulation is a useful technique when micronutrients are added to certain staples like rice and wheat to fortify them.[8,23,24,25]

FOOD INDUSTRY	**PHARMACEUTICAL INDUSTRY**	**OTHER INDUSTRIES**
Functional foods	**Specific drug delivery**	**Textile industries**
Probiotics Antioxidants Vitamins Dietary fibers Food preservatives Food colorants Food flavors	Oral drug delivery Transdermal drug delivery Stomach-specific drug delivery Colon-specific drug delivery Small intestine-specific drug delivery Bitter taste-masking	Fragrance finishing Color change materials Fire retardants
		Cosmetic industries

		Essential oils Polyphenolic compounds

Tableiapplication of Microencapsulation on Different Industries

Recent applications of microencapsulation of microbial cells in various biotechnology materials by process:

1. The food industry has been the primary driver of commercial success for microencapsulation, with the main application being probiotics; other uses for encapsulated cells include environmental decontamination and microorganism fermentation. Microencapsulation has also been used to immobilize cells for a few applications due to its ratable benefits and flexibility to a broad range of materials and techniques. [8,27,28]

2. Because microencapsulation has so many advantages and can be applied to so many different materials and procedures, it has been employed in a few different contexts to immobilize cells. Nonetheless, the primary driver of commercial success in the food business has been probiotic microencapsulation. In addition to probiotics, encapsulated cells have been employed in the fermentation of microorganisms and environmental cleanup. [29,30]

Conclusion:

The technique of enclosing an active component in a capsule that ranges in size from a few microns to several millimeters is known as "microencapsulation". The capsule isolates the active substance from its environment till the right time. The material then manages to escape the capsule wall via several different mechanisms, including disintegration, melting, diffusion, or rupture. Microencapsulation is both an art and a science. There's no one right way to accomplish things, and each application has its own unique set of challenges. These challenges demand experience, competence, and knowledge of a wide range of technology. They are vulnerable to chemical instability and degradation, though. Microencapsulation is a practical and efficient process used in a range of sectors to increase the chemical, oxidative, and thermal stability of oil-based, high-quality, and health-beneficial products. Furthermore, it is possible to enhance the oils' overall quality, controlled release, biological activity, functional activity, shelf life, and physicochemical properties. Spray drying and coacervation are the two most popular techniques for encapsulating oils.

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