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DESIGN AND OPTIMIZATION OF AIR SUSPENSION MICROENCAPSULATION PROCESS

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ABSTRACT

Microencapsulation is a versatile and well-established technology used to entrap solid, liquid, or gaseous core materials within a protective coating to enhance stability, control release, and improve handling properties. The analyzed articles collectively highlight the fundamental principles, materials, techniques, and applications of microencapsulation across pharmaceutical, food, agricultural, textile, and construction industries. Various core and coating materials, including polymers, proteins, and lipids, are discussed with emphasis on their compatibility, biodegradability, and release characteristics. The articles also address microcapsule morphology, release mechanisms, and factors influencing encapsulation efficiency. Despite its advantages, challenges such as high production costs, scalability issues, and non-uniform particle size are noted. Overall, the reviewed literature demonstrates that microencapsulation is a critical enabling technology with significant potential for innovation, especially when optimized materials and methods are selected to meet specific application requirements.

Keywords: *Release mechanisms, Microspheres, Controlled drug release, Microcapsules*

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1. INTRODUCTION

The method of micro-encapsulation involves enclosing microscopic particles or droplets in a covering to create tiny capsules. While the wall is frequently referred to as a shell, covering, or membrane, the substance inside the microcapsule is known as the core, internal phase, or fill [1]. It also goes by the name "micro balloons." procedure for encasing inert shells around microscopic solid, liquid, or gas droplets. The process of microencapsulation typically consists of four stages: integration, solidification, and the development of the core and encapsulants. The technology in question is not new; it was first used in a business setting for carbonless copy paper in 1954 [2]. The pharmaceutical industry has developed many coating materials and application procedures for the microencapsulation of medications.

Pharmaceutical businesses that produce microencapsulated medications have obtained multiple patents within the past 25 years. The development of several microencapsulated materials, including medications, was sparked by the breakthrough made in the 1950s with duplicate paper and ribbons that held dyes in tiny gelatin pills that were activated by a typewriter key or the pressure of a pen or pencil. Typically, microspheres are free flowing powders made of proteins or synthetic polymers that are biodegradable and ideally have a particle length of much less than two hundred μm.

Bio is the component of microencapsulation. These microencapsulated products vary in size from 1 to 1000 μm in diameter and can contain 10-90% of the core material. Different bioactive compounds, such as omega-3 and omega-6 fatty acids, vitamins, phenolic compounds, and carotenoids are now widely used to develop products with numerous functional properties to meet up the increasing consumer demands. However, such compounds are highly unstable under certain conditions of light, temperature, pH, and oxygen. Some coating materials include carbohydrates such as starch, maltodextrin, modified starch, cyclodextrin, cellulose; lipids such as wax, paraffin, beeswax, diacylglycerols; gums such as gum acacia, agar, carrageenan; and proteins such as gluten, casein, and gelatine. Depending on the kind of coating material used, different techniques are used to produce the microcapsules and these techniques lead to differences

in the properties of the capsules like capsule size, morphology, porosity, hygroscopicity, hydrophobicity, surface tension, and thermal behavior [3].

Additionally, it covers various microencapsulation methods, microcapsule characteristics such as mechanical, thermal, functional, and physical, as well as various core release mechanisms. Additionally, it demonstrates the technology's applicability in the food industry. The materials that surround the microcapsules are called coating materials, wall materials, shells, or membranes, while the materials that are inside them are called core materials, pay-load materials, or nuclei [4].

2. PRINCIPLES OF MICROENCAPSULATION:

- Microencapsulation involves the creation of micro-sized capsules, which are often composed of polymers, lipids, or other materials.
- These capsules encapsulate a core material, which can be a solid, liquid, or even a gas.
- The protective shell or coating serves to control the release of the core material, protecting it from external factors.
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3. NEED FOR MICROENCAPSULATION IN FOODS:

3.1 Protection and improved delivery

Functional foods can be made using a variety of ingredients, such as probiotics, fermentation microorganisms, and essential oils, which have several advantages like antioxidant and antibacterial qualities. Encapsulation has so shown itself to be a one-stop shop for these issues. For its antimicrobial properties, Piletti et al. (2019) used β-cyclodextrin to encapsulate garlic oil as a heat protection technique (2018) used soybean protein-based coating material for improved delivery of probiotics in the gut [5].

3.2 Controlled release

Encapsulated functional components like certain vitamins, flavors, or essential oils when incorporated in the food matrix are of importance only when they are released at a particular location in the body or at a particular time, for example, encapsulated flavors in chewing gum are released only when the gum is chewed. These include (a) burst-release mechanism, this is basically used in case of encapsulated probiotics, (b) thermal degradation, where the coating material degrades at a particular temperature and the core is released and few others, which are described further in the other section [6]. Entrapment of the compound in a biopolymer gel delayed the flavor release up to three folds during cooking, hence, releasing it at a later stage of cooking.

3.3 Masking of flavor and odor

Before adding particular substances to any dish, their unwanted flavour and aroma can be covered up via microencapsulation. For example, microencapsulation allows the use of fish oil and some bitter-tasting substances in food without giving it a disagreeable flavour or odour. Using modified starch and maltodextrin as the carrier agents, Breternitz et al. (2017) demonstrated that the bitter taste of mussel protein hydrolysate could be effectively covered up by spray drying it. Similarly, maltodextrin and inulin were used to microencapsulate isoflavones, masking their disagreeable taste and odour (Wyspianska et al., 2019) [7].

3.4 ADVANTAGES [8,9]

- Resistance to warmth exceptional intermediate chemical that may be applied to a solid product Controlled actives' release hydrophobic actives' solubility reduces the compound's lack of volatility.
- Low operating cost suitable for heat-sensitive actives
- Cost-effective techniques that don't require high temperatures or the usage of natural solvents in certain pH ranges for their development.
- A good substitute for a temperature-sensitive substance.
- It improves the ability of poorly soluble drugs

3.5 DISADVANTAGES [8,9]:

- The use of thermo labile compounds is no longer recommended since nonuniform waste can shape aggregate
- Unique rather than depending on fabric with drastically fluctuating encapsulation efficiency and natural solvent use.
- Aggregate can be shaped by steeply priced materials limited to low molecular weight.
- Unique product challenges with viscous solution in terms of size and shape.
- The expense of the foam texture product made gradually.

5. REASONS FOR MICROENCAPSULATION

- The first reason for microencapsulation is for supported or expanded sendoff of the medication
- The strategy has been comprehensively utilized for covering the organoleptic houses like flavor and smell of numerous tablets and appropriately further develops Patient consistence for example Paracetamol, Nitrofurantoine for covering the sharp flavor.
- Microencapsulation can be used to include the tablets that are sensitive to light, moisture, and oxygen. For instance, nifedipine is incorporated from picture chart unsteadiness.
- Microencapsulation can help reduce toxicity and GI discomfort, especially when combined with ferrous sulphate and KCL [10].

6. CLASSIFICATION OF MICROENCAPSULATION

Microencapsulation of Classification

6.1 Physical Method

During the physical process, the shell is compressed mechanically above the main active ingredient without engaging in any chemical reactions, resulting in microcapsules that have an average diameter greater than 100 μm. Spray drying, centrifugal extrusion, fluidised bed, air-suspension coating, electrohydrodynamics, and pan-coating are all well-liked due to their benefits, which include lower production costs, less energy consumption, and compatibility with temperature-sensitive items like food and biological products [11,12]. However, the availability of shell processes, which are all commonly used physical approaches, limits the efficacy of this approach.

Spray drying method

The spray drying method, developed in the 1930s, is a straightforward and easily reproducible drying technique that is also scalable. It has high encapsulation efficiency materials that can dissolve in water, such as hydrophilic materials [13].

Solvent Evaporation Method

Solvent evaporation occurs routinely in nature when water gains energy, often as heat, and transitions from a liquid state into a gaseous one. Thermal molecular agitation is what underlies this change, hence you apply heat to water and molecules with energy in excess of the thermodynamic potential escape from the water surface as water vapour.

6.2 Methods of solvent Evaporation

Rotary Evaporation

A rotary evaporator is employed for the precise and cautious removal of solvents. Rotary evaporation involves rotating a solvent in a vacuum to increase surface area, lower the pressure to decrease boiling point of the solvent, and heat the solution. The procedure decreases the likelihood of collisions and enables a gradual evaporation process.

Tube Evaporation

Evaporating solvents from parallel tubes is part of the tube evaporation process. It is a quick and effective technique that reduces the chance of solvent bumping. Tube evaporation enables the concentration of high boiling solvents without needing to subject them to high temperatures. These solvent options consist of DMSO, DMF, and water.

Centrifugal Evaporation

Centrifugal evaporators are used for evaporating multiple liquid solvents at low temperatures. A vacuum pump is utilized to facilitate solvent evaporation for removing solvents from the samples; nevertheless, as this takes place in a vacuum, the samples become cold Boiling samples with surface-down orientation decreases the chance of cross-contamination and sample loss.

6.3 Chemical Methods of Microencapsulation:

In-situ Polymerization

Only a microencapsulation small number of methods entail directly polymerizing a monomer on the surface of the particle. During a single process, for example, cellulose fibers are enclosed in polyethylene while being surrounded by dry toluene. The coating thickness varies from 0.2 to 75 micrometers. The uniform coating covers sharp projections [14].

Interfacial Polymerization:

Interfacial polymerization saw significant advancements in the late 1960s eventually leading to the production of microcapsules by the mid-1970s. One important aspect of microencapsulation through interfacial polymerization is the movement of the reagents to the reaction boundary [15].

Suspension Polymerization:

This chemical process is employed in certain encapsulation techniques to produce coreshell particles. During the initial stage, microdroplets are created by mixing the monomer phase, which includes monomers, a blowing agent, and an initiator, with a stabilizing agent in a medium using a stirrer. The polymer separates from the monomer droplets due to its lack of solubility. A mixture is created with monomer, polymer, and water in a three-phase system.

Emulsion Polymerization Method:

Emulsion polymerization is a form of radical polymerization common in polymer chemistry, typically initiated by an emulsion containing water, monomer, and surfactant. The prevalent form of emulsion polymerization is an oil-in-water emulsion, where monomer droplets (the oil) are emulsified (using surfactants) in a continual water phase This layer repels other particles as compressing the chains would be necessary to push particles together.

6.4 Physical–Chemical Methods

Coacervation Method:

Coacervation is a popular and effective technology for encapsulating probiotics. It operates by creating a liquid with a high polymer concentration that is in balance with another liquid phase. Different researchers have examined how the coacervation process impacts probiotics.

Sol–Gel Method:

The S-G method, short for sol-gel method, involves using a compound with a highly reactive component as a precursor, mixing these materials uniformly in liquid form, and then carrying out hydrolysis and condensation reactions to create a stable and transparent sol system in solution.

7. TECHNIQUES TO MANUFACTURE MICROCAPSULES

7.1 Physical Methods:

Pan Coating

- The most well-known modern method for encasing small, coated particles or tablets is the dish covering procedure, which is widely used in the pharmaceutical industry.

- The technique uses heated air in conjunction with a covering piece to move a sleeping cushion of trash in order to facilitate the dissolvable disappearance.

7.2 Air Suspension Method

The two processes in the air suspension process are the spraying of coating material in the air suspended particles and the dispersion of the core materials in a supporting air stream. Depending on the required coating thickness and whether the core material particles are completely encased, the cyclic process is repeated a few times [16].

7.3 Spray Draying

When an active ingredient dissolves or suspends in a melt or polymer solution and gets trapped in the dried particle, spray drying functions as a microencapsulation process. Ordinarily, the molecule size of splash solidified items can be precisely controlled when shower drying gear is utilized, and has been viewed as a component of the feed rate, the atomizing wheel speed, scattering of feed material thickness, and factors.

7.4 Centrifugal Extrusion

coating substances are co-extruded thru the concentric orifices of the nozzles as a fluid rod of the center sheathed in coating cloth. Centrifugal pressure impels the rod outward, inflicting Any other encapsulating technique that a few manufacturers have looked into and used is centrifugal extrusion. Particles delivered strategy have a measurement beginning from 100 and fifty to 2000 mm.

7.5 Physico-chemical Method

Coacervation:

Coacervation, also referred to as "segment partition," is regarded as a true microencapsulation technique due to the fact that the core texture is completely entrapped by the framework's method of approach.

7.6 Chemical Method

Polymerization

Interfacial Polymerization

In interfacial polymerisation, the two reactants in a polycondensation converge at an interface and undergo a fast reaction. A pesticide and a diacid chloride are emulsified in water to create an aqueous solution, to which an amine and a polyfunctional isocyanate are added. The walls of condensed polymers are immediately visible at the emulsion droplet contact.

In-Situ Polymerization

Similar to IFP, the polymerisation of monomers introduced to the embodiment reactor results in the pill shell arrangement. No receptive retailers are brought to the central material using this procedure with the instruction to use areas of strength for shell delivery, it stores on the floor of the dispersed center material.

Matrix Polymer

In different cycles, as the particles evolve, a core substance becomes embedded in a polymeric network. Splash drying is a fundamental technique for this kind of process, where the dissolvable substance dissipates to shape the molecule. Eurand America and the Public Lead Organization serve as models [17].

8. CHARACTERIZATION OF MICROCAPSULES [18]

- Particle size and shape
- Fourier transform-infrared spectroscopy (FTIR)
- Carr's index and Hausner's ratio
- Bulk density

9. APPLICATION OF MICROENCAPSULATION [19]

- Food
- Beverage
- Cosmetics

10. CURRENT & FUTURE DEVELOPMENT

Considering the encapsulation goal, methodology, shell or matrix formers, pharmaceuticals, and active agents, this review focused on analysing the most current and, if necessary, the oldest patents that employ emulsion solvent removal techniques for drug and physiologically active agent encapsulation. As a result, preparation methods that can generate more microspheres in a safe, controlled, economical, and dependable manner are required [20].

11. CONCLUSION

A procedure known as "microencapsulation" involves enclosing an active ingredient in a capsule that ranges in size from one micron to several millimetres. Microencapsulation is both an art and a science. For many medications, microspheres and microcapsules are system-specific and can be altered to stick to the target tissue. Particularly significant are the advancement of worldwide research, particularly for bioadhesive microspheres, and the creation of less expensive biopolymers for microencapsulation technology. Microencapsulation is the technique of enclosing an active ingredient in a capsule that can be anything from one micron to several millimetres in size. The capsule protects the active ingredient from the environment until the right moment. The material then breaks through the capsule wall, melts, dissolves, or diffuses.

12. AUTHOR CONTRIBUTIONS

All authors are contributed equally.

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14. DECLARATION COMPETING INTEREST

The authors have no conflicts of interest to declare.

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