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MICRO ENCAPSULATION: FROM CONCEPT TO COMMERCIAL APPLICTIONS

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ABSTRACT

This review article delves into the dynamic realm of microencapsulation, a technology that encapsulates active ingredients within microscopic particles. The membrane dissolves itself when stimulated, releasing the core at the desired time or place. Microencapsulation has many applications in the food, agricultural, pharmaceutical, and medical industries. It has been used in flavours, acids, oils, vitamins, and microorganisms. This article comprehensively explores various microencapsulation techniques, ranging from traditional methods to state-of-the-art technologies. Microencapsulation offers the crucial functionality of controlling the release of food ingredients at precise locations and timings, ensuring optimal effectiveness. It examines the applications of microencapsulation in different industries including pharmaceutical, agriculture, food, printing, cosmetic, textile and defence. Also highlighting its impact on product stability, controlled release and enhanced performance in different areas of science and technology. In the realm of pharmaceuticals and various other industries, microencapsulation plays a crucial role in enhancing stability, protecting sensitive substances and regulating the release of active ingredients. Microencapsulation is garnering significant attention across various domains including commercial development and research.

INTRODUCTION

Microencapsulation is a rapidly expanding technology in many consumer goods to protect and deliver active ingredients at end-use applications [1]. Specifically, active ingredients i.e. solid materials, liquid droplets or gaseous molecules are entrapped within an inert shell consisting of synthetic [2, 3]. and/or bio inspired, materials, which are able to segregate chemically and thermally unstable active ingredients from adverse environmental conditions (e.g. light, oxidation, and pH changes) [4]. The earliest microencapsulation technologies arose during the first half of the twentieth century with the fabrication of gelatin-gum Arabic microcapsules via complex coacervation for carbonless copying paper [5]. The method of micro-encapsulation involves enclosing microscopic particles or droplets in a covering to create tiny capsules. A microcapsule is a tiny spherical with a homogeneous wall surrounding it in its most basic form. 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 [6]. It also goes by the name "micro balloons." procedure for encasing inert shells around microscopic solid, liquid, or gas droplets. The physical and chemical characteristics of the capsules are dictated by the material selection for the shell. Therefore, the choice of shell material must take into account a number of crucial criteria in order to accomplish the intended goal of encapsulation, including the needs of the product, the environment, the characteristics of release, and compatibility with the micro-encapsulation technique. The process of microencapsulation typically consists of four stages: integration, solidification, and the development of the core and encapsulants. Spray chilling, spray cooling, fluidized bed coating, liposome entrapment, extrusion, freeze drying, and coacervation are only a few of the many methods used in microencapsulation [7].

This can lead to the development of prolonged controlled release dosage forms, ultimately improving patient compliance and therapeutic outcomes. Various techniques have been developed and employed for microencapsulation, each with its unique principles and advantages. These include air suspension, coacervation phase separation, pan coating, spray drying and spray congealing, and solvent evaporation. The choice of technique depends on factors such as the nature of the

active ingredient, desired release profile, and production scale [8].

1.PRINCIPLE

Microencapsulation is a versatile technique that employs a multidisciplinary scientific approach to improve human health through controlled drug delivery. This section will delve into the fundamental principles and various techniques employed in microencapsulation. A microparticle is generally defined as any particle with a diameter ranging from 1 to 1000 μm, regardless of its interior or exterior structure. Within the broad category of microparticles, "microspheres" specifically refer to spherical microparticles, while "microcapsules" refer to microparticles with a core made of a material that differs significantly from the shell, which can be solid, liquid, or even gas. A microcapsule is a spherical particle with a core substance and a size ranging from 50 nm to 2 mm. It is important to note that the terms "microsphere" and "microcapsule" are sometimes used interchangeably, despite their distinct definitions. Other related terms, such as "microbeads" and "beads," are also used synonymously [9,10]

2. REASONS FOR MICROENCAPSULATION

Extended or sustained drug release: Microencapsulation is widely utilized to achieve sustained release of drugs, improving patient compliance and therapeutic outcomes.Taste and odour masking: Microencapsulation can enhance patient acceptability and adherence by encapsulating drugs with unpleasant tastes or odours.Microencapsulation also helps to prevent incompatibilities among drugs and prevents the vaporizations of volatile drugs like methyl salicylate and peppermint oil [11].The primary goal of microencapsulation is to provide a medication with delayed or sustained release [12].

3.COATING MATERIALS AND THEIR PROPERTIES

3.1 coating material

A coherent, chemically well-matched, and nonreactive movie that is formed by the coating cloth and the centre cloth should be possible. stability using the centre cloth, Apathetic towards components with energy, the coating may be thin, hard, brittle, flexible, or launched under specified conditions. Easily accessible and reasonably priced. Strength, flexibility, impermeability, stability, and optical qualities are among the other desired coating features that are provided. Some degree of in situ modification is possible for the coating materials used in microencapsulation procedures. The selection of a particular coating can be facilitated by examining recent literature and watching uncut or fake films; however, the practical application of uncut film records is hindered for the following reasons [13].

3.2 properties of coating material:

- Microencapsulation helps stabilize the core material protecting it from degradation caused by external factors such as light, moisture and oxygen.
- The encapsulation process results in a film forming, tasteless, pliable, and stable coating around the core material.
- The material for microencapsulation should be soluble in aqueous media or solvent or capable of melting, facilitating the encapsulation process [14].

4.FACTORS INFLUENCING ENCAPSULATION EFFICIENCY

There exist multiple characteristics that impact the encapsulation effectiveness of micro particles, microcapsules, and microspheres. The various factors affecting encapsulation efficiency are shown in Figure [15].

- Volume fraction of both dispersed to continues phase.
- Drug quantity in dispersed phase
- Surfactant concentration.
- Operating parameters.
- Agitation rate/time.
- Temperature.
- Geometry of agitator and reactor.

5.CLASSIFICATION OF MICROENCAPSULATION

1. Mononuclear: Mononuclear microcapsules consist of a core-shell structure, with the shell surrounding the core.
2. Poly-nuclear: Poly-nuclear capsules feature multiple cores enclosed within a single shell structure.
3. Matrix type: In matrix encapsulation, the core material is uniformly distributed within the shell material [16].

6. MICROENCAPSULATION TECHNIQUES

(A): Physical Methods:

- Air suspension coating
- Pan coating
- Centrifugal extrusion

(B): Chemical Methods:

- Coacervation Phase separation
- Matrix polymerization
- Solvent evaporation

6.1 air-suspension coating:

Professor Dale E. Wurster created the air suspension coating method while he was employed at the University of Wisconsin's Department of Pharmacy. The air suspension apparatus is divided into various elements, including the coating chamber, air distribution plate, control panel, and nozzle used to apply film coatings. Particles are suspended in the coating chamber of the air suspension apparatus by an upward-moving air stream. Coating material is sprayed onto the moving core particles in the coating zone.

The recirculating flow of the core particles through the coating zone is influenced by the chamber's design and operational settings. With each pass through the coating zone, the core material gets a little bit more coating material-typically a polymer solution. The cycle is continued until the required coating thickness is attained. During the encapsulation process, the supporting air stream aids in drying the product. Typically, air suspension methods are limited to encasing the solid core components. The encapsulating materials had a major influence on the pace at which the medication was released from the microcapsules [17].

6.2 pan coating:

One of the earliest methods used in industry to generate small, coated particles is the pan coating technique, which finds widespread application in the pharmaceutical sector. While applying the coating material gently, the particles are tumbling in a pan. Solid particles larger than 600 μm are usually thought to be necessary for efficient coating in the context of microencapsulation. Applying the coating on the chosen solid core material in the coating pan can be done in two ways: as an atomized spray or as a solution. As the coatings are applied in the coating pans, heated air is typically passed over the coated items to remove the coating solvent. The last step of solvent elimination is sometimes completed in a drying oven [14].

6.3 coacervation process

Coacervation, also referred to as "phase separation," is regarded as a genuine microencapsulation method since the matrix entirely encloses the core substance. This method entails the precipitation or division of an aqueous phase from a colloidal phase [18]. Using this technique, one or more hydrocolloids that are suspended in the same reaction media are phase separated from a polymeric solution layer around the core.

Material. Coacervates are formed over a limited pH range and involve the electrostatic interaction of two biopolymers with opposing charges. Using this method, the polymer-rich (coacervate) phase and the liquid phase separate [19]. The coating material solution is used to spread the core material during this operation. The maximum solubility of the core material in the coating material's solvent is 2%; it should not react or dissolve in it. Dispersion characteristics, including surface tension, viscosity, stirrer shape, and stirring speed, determine the size of the particles. The range of particle sizes is 2μm–1200μm. The first step in aggravating a dispersion's pH is to add H2SO4, HCl, or organic acids, for example. The dispersion phase's (shell material's) solubility is lowered as a result.

6.4 matrix polymer:

A core material is inserted by a variety of processes into a polymeric matrix during the particle's production. This type of fundamental process, known as spray-drying, creates the particle by allowing the solvent to evaporate from the matrix material. However, the matrix's solidification could also be the result of a chemical change. Using this phenomenon, Chang incorporates the protein into the aqueous diamine phase to create protein solutions in microcapsules. Chang has established the perm selectivity by demonstrating the conversion of blood urea to ammonia, the enzyme that stays in the microcapsules when integrated into an extracorporeal shunt system. To accomplish microencapsulation, numerous groups are using polymerization techniques. Two instances are the National Lead Corporation and Aurand America [20].

7. ADVANTAGES AND DISADVANTAGES OF MICROENCAPSULATION

7.1. Advantages

Microencapsulation offers numerous advantages, making it a valuable technology in various industries, including pharmaceuticals, cosmetics, and agriculture:

- Protection of encapsulated active agents or core components from environmental factors, such as light, moisture, and oxygen [21]
- Transformation of gases and liquids into solid particles, facilitating handling and storage.
- Controlled actives' release hydrophobic actives' solubility reduces the compound's lack of volatility

7.2 Disadvantages

Microencapsulation offers numerous advantages, making it a valuable technology in various industries, including pharmaceuticals, cosmetics, and agriculture.

- Reduced shelf-life for hygroscopic agents: Hygroscopic agents encapsulated within the microparticles may have a shortened shelf-life due to potential moisture absorption.
- Uneven coating: Inconsistencies in the microencapsulation coating can affect the release of encapsulated materials, potentially leading to variability in performance.
- Aggregate can be shaped by steeply priced materials limited to low molecular weight [22].

8.APPLICATIONS OF MICROENCAPSULATON

Microencapsulation finds numerous applications across various industries due to its versatility and ability to impart beneficial properties to encapsulated substances. Some notable applications include:

8.1 Pharmaceutical industry

- Extended or sustained drug release formulations
- Taste and odour masking of bitter or unpleasant drugs
- Targeted drug delivery to specific sites

8.2 Food industry

- Encapsulation of Flavors, colours, and nutrients
- Protection of sensitive ingredients from degradation
- Controlled release of Flavors or aromas

8.3 Agrochemical industry
- Controlled release of pesticides, herbicides, and fertilizers
- Protection of active ingredients from environmental factors
- Reduction of environmental impact through targeted delivery.

Some applications commonly used are
1. Paper exports without carbon
2. Sniffing and scratching
3. Perfume and taste
4. Microencapsulation has medical applications.
5. Microencapsulation: everyday use (mineral (iron) and vitamin encapsulation)
6. Formulation (oral and injectable medicinal formulations)

9. LIMITATIONS OF MICROENCAPSULATIONS

Microencapsulation is a powerful technique for controlled release and protection of active ingredients, but it comes with several limitations such as high production costs, complexity in scaling up, instability of capsules under certain conditions, and challenges in achieving uniform particle size.Key Limitations of Microencapsulation

9.1 High cost and complexity

Scale-up difficulties: Laboratory success often doesn't translate easily to industrial-scale production due to process sensitivity.

9.2. Stability issues

Environmental sensitivity: Capsules may degrade under heat, humidity, or light exposure.

9.3. Regulatory and safety concerns

Toxicity of materials: Some polymers or solvents used may not be biocompatible or safe for pharmaceutical/food use.

10. CURRENT AND FUTURE PERSPECTIVES

This review concentrated on examining the most recent and, if required, the oldest patents that use emulsion solvent removal techniques for drug and biologically active agent encapsulation, taking into account the encapsulation goal, methodology, shell or matrix formers, and drugs or active agents. Large scale microsphere production remains a challenge, despite the annual emergence of new patents utilizing the emulsion solvent removal process to create robust, consistent, and highly reproducible microparticles. Furthermore, before the microparticle may be utilized for other purposes, it needs to undergo a thorough washing procedure to eliminate the solvent. These drawbacks lead to inefficiencies, which raise the price of the resulting microparticle. Furthermore, the organic solvent that was used to create the microemulsion is a dangerous substance that should be handled, stored, and disposed of with caution due to its potential risks to human health and the environment. In light of this, it is expected that future years will bring forth even more creative concepts, such as a notable enhancement of the physicochemical and toxicological characteristics of the commercial formulations. Therefore, it is necessary to have preparation technologies that can produce more microspheres in a way that is reliable, affordable, safe, and well-controlled [23].

11.CONCLUSION

One way to preserve the quality of delicate materials is by microencapsulation, which is also a process for creating new, valuable materials. The most practical method for protecting and masking, lowering the rate of dissolution, making handling easier, and spatially targeting active chemicals is the widely used microencapsulation approach. The process of encapsulating an active component inside a capsule that ranges in size from a single micron to several millimeters is known as microencapsulation. Until the proper time, the capsule shields the active substance from its surroundings. The substance then melts, dissolves, diffuses, or ruptures through the capsule wall. For medications that need to dissolve in the intestine rather than the stomach, the microencapsulation method is also advantageous.

12. AUTHOR CONTRIBUTIONS

All authors are contributed equally.

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The authors have no conflicts of interest to declare.

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