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An overview of Microencapsulation : Fundamentals, Applications, characteristics, and methodologies

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A B S T R A C T :

This review article immerse into the performing microencapsulation is a technics that involved the encapsulation of deed full material within a protecting matrix. This matrix shields the active material from the environment, controlling its release and improving its stability. Microencapsulation has applications in pharmaceuticals, food, cosmetics, and agriculture. the encapsulation process involves forming a thin membrane around the active material. Various techniques are used, including spray drying, emulsion, coacervation, and liposome formation. The choice of technique and matrix material depends on the application and desired release profile. Microencapsulation offers improved stability, controlled release, and increased bioavailability. It enables targeted delivery, reducing side effects and improving efficacy. Microencapsulation also enhances shelf life, reduces waste, and improves sustainability. 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 material. Microencapsulation is garnering significant attention across various domains including commercial growth and research. This technics brings a big effect in the area of pharmaceutical research which also offers common appearance in controlled and target drug delivery method.

Keywords: Microencapsulation methods, microcapsule, pharmaceuticals, benefits, application.

Introduction:

Microencapsulation is a systematic process in which very small particle of liquid or solid matter surrounded covered by a continuous polymer film of substance. Microencapsulation is the process of packaging for solid, liquid or gas substance in the second material to protect the environmental operations the environment.

The operating particle is considered a central particle while the surrounding materials act as shells. This technique has been used in many pharmaceutical industry, chemicals and pharmaceutical products with cosmetic and printing products. The concept of this packaging is the number of micro substances in microspheres from the 1930s. Micro encapsulation has its roots in the 1950s, when scientists first began exploring the use of encapsulation to deliver drugs and other active material. Since then, the field has evolved significantly, with advanced, in substance nanotechnology [3, 4, 5]

These micro-capsules have a number of advantage such as converting liquids to solid separating reactive, material providing environmental protection, improved substance handling properties. Active materials are then encapsulated in micron-sized capsules of barrier polymer [6]

Microencapsulation methods exist, including spray drying, and polymer-based encapsulation, each chosen based on the characteristics of the core material and the desired application. In the pharmaceutical field, microencapsulation is crucial for controlled drug release, reducing side effects, and improving patient compliance. In food technology, it is used for flavor retention, nutrient protection, and probiotic delivery. Ongoing research continues to refine microencapsulation processes, making them more efficient and expanding their applications in new industries. [7]

1933: Vincenzo Bisceglie pioneered the encapsulation of tumour cells in polymer membranes, demonstrating that these encapsulated cells remained viable without eliciting an immune impedance when transplanted into pigs.

1964: Thomas Chang introduced the concept of artificial cells, proposing that encapsulating cells within ultra-thin polymer membranes could provide immunoprotection, allowing the encapsulated cells to function without being attacked by the host's immune system.

1980s: The development of alginate-polyline-alginate (APA) microcapsules marked a significant advancement. Researchers demonstrated that cells encapsulated within these microcapsules could regulate glucose levels in diabetic rats for several weeks, highlighting the Potential of microencapsulation in therapeutic use.[8]

ADVANTAGES OF MICROENCAPSULATION

- **Protection of Active material;** microencapsulation safeguard sensitive compounds from environmental factors such as light, moisture, and oxygen, thereby enhancing their stability and shelf life.

- **Controlled Release;** It enables the controlled and targeted release of active ingredients, ensuring they are delivered at the desired rate and location within the body.
- **Masking Unpleasant Properties**: The technique can mask undesirable tastes, odors, or colours of certain substances,
- **Improved Handling and Processing**; by converting liquids into solid particles, microencapsulation facilitates easier handling, enhances flow properties, and reduces volatility of core materials.
- **Enhanced Bioavailability:** Microencapsulation can improve the solubility and bioavailability of poorly water-soluble compounds, leading to effective therapeutic outcomes.
- **Separation of Incompatible material:** It allows for the incorporation of incompatible ingredients within the same formulation by preventing premature interactions between them.[All 9,10,11]

DISADVANTAGES OF MICRO ENCAPSULATION.

- **High Cost;** One of the main disadvantages of microencapsulation is its high cost. The process requires specialized equipment and expertise, which can be expensive.
- **Scalability Issues;** microencapsulation is its scalability issues. The process can be difficult to scale up for large-scale production, which can limit its commercial viability.
- **Limited Control over Release;** Microencapsulation can provide controlled release, but it can be difficult to achieve precise control over the release rate. This can affect the efficacy of the encapsulated ingredients.
- **Instability of Encapsulated material;**
  Encapsulated ingredients can degrade over time, which can affect their potency and efficacy [10, 11]
- **Difficulty in Achieving Uniform Particle Size;** Uniform particle size can be difficult to achieve, which can affect the release rate and efficacy of the encapsulated ingredients**.**
- **Limited Flexibility;**
  Microencapsulation can be inflexible, making it difficult to change the formulation or process conditions**.**
- **High Energy Requirements;**
  Microencapsulation can require high energy inputs, which can increase costs and affect the environment**.**
- **Regulatory Challenges;**
  Microencapsulation can be subject to regulatory challenges, particularly in the pharmaceutical and food industries**.**

APPLICATION OF MICROENCAPSULATION

PHARMACEUTICAL APPLICATIONS:

1. **1. Controlled release:** A longer- lasting reliable release profile is made believable by employing microencapsulation to control the release of medications.
2. **Improved bioavailability:** Microencapsulation is used to improve the bioavailability of drugs, allowing for more effective treatment.
3. **Reduced side effects:** Microencapsulation is used to reduce the side effects of drugs, improving patient comfort and safety.

Targeted Delivery;

microencapsulation, medications can be administered to specific bodily parts. [1, 2]

FOOD APPLICATIONS;

1. **Improved nutrient delivery:** Microencapsulation is used to improve the delivery of nutrients, such as vitamins and minerals.
2. **Increased shelf life:** Microencapsulation is used to increase the shelf life of food products, reducing waste and improving food safety.
3. **Enhanced flavour;** Microencapsulation is used to enhance the flavour and aroma of food products, improving consumer satisfaction.
4. **Reduced oxidation:** Microencapsulation is used to reduce the oxidation of food products, improving their nutritional value and shelf life. [1, 2]

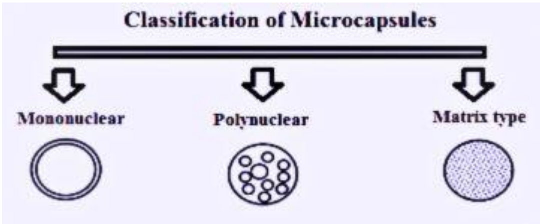
COSMETIC APPLICATIONS:

1. **Improved skin penetration:** Microencapsulation is used to improve the penetration of active ingredients into the skin, enhancing their effectiveness.
2. **Increased stability;**
3. Microencapsulation is used to growth the stability of active material, reducing degradation and improving shelf life.
4. **Enhanced moisturization:** Microencapsulation is used to enhance the moisturization of the skin, improving skin hydration and comfort.
5. **Reduced irritation:** Microencapsulation is used to reduce the
   Irritation caused by active ingredients, improving skin safety and comfort. [11]

AGRICULTURAL APPLICATIONS

1. **Improved pest control:** Microencapsulation is used to improve the control of pests, reducing crop damage and improving yields.
2. **Increased fertilizer efficiency**: Microencapsulation is used to growth the efficiency of fertilizers, reducing waste and improving crop increase.
3. **Reduced environmental impact:** Microencapsulation is used to reduce the environmental effect of pesticides and fertilizers, improving soil and water quality.
4. **mproved crop safety:** Microencapsulation is used to increase the safety of crops, reducing the risk of contamination and improving different food safety. [11]

CLASSIFICATION OF MICROENCAPSULATION



1. Mononuclear.
Mononuclear microcapsules are a type of microcapsule that consists of a single nucleus or core surrounded by a polymeric membrane [13]. These microcapsules' capacity to enhance stability, regulate release, and deliver active ingredients to specific locations has led to their widespread application in a variety of industries, including food science, biotechnology, and medicines [14-15].

2. Poly nuclear. A polymeric membrane encasing multi-nuclear or multi-core microcapsules is called a poly nuclear microcapsule. Many different industries, such as biotechnology, medicine, and food science, have made extensive use of these microcapsules. It has numerous benefits, including enhanced stability, controlled release, and targeted active component distribution. Applications have been studied in a variety of domains, including medicine delivery, food packaging, and cosmetics.

3. Matrix.
Microencapsulation is the process of encasing active ingredients in a protective matrix. Matrix microcapsules are a type of microcapsule that consists of a matrix of polymer or other materials that surrounds the active ingredient.

Matrix microcapsules have been used in various fields to improve stability, control release, and target delivery of active ingredients. [16-17]

IMPORTANT FEATURES OF MICROCAPSULES

1. **Small Size:** Microcapsules are tiny capsules that range in size from a few micrometres to several millimetres.
2. **Encapsulation:** A variety of active compounds, including medications, flavours, perfumes, and nutrients, can be encapsulated in microcapsules**.**
3. **Targeted Delivery:** Microcapsules can be engineered to target specific sites in the body, which can improve the efficacy of the active ingredient and reduce side effects.
4. **Improved Stability:** Microcapsules can protect the active ingredient from degradation, oxidation, or other forms of damage, which can improve its shelf life.
5. **Biocompatibility:** Microcapsules can be made from biocompatible materials, which can reduce the risk of adverse reactions or toxicity.
6. **Flexibility:** Microcapsules can be formulated in a variety of shapes, sizes, and materials, which can be tailored to specific applications.
7. **Scalability:** Microcapsules can be produced on a large scale using various manufacturing techniques, which can make them more cost-effective.

METHODS OF PREPARATION OF MICROENCAPSULATION

1. AIR SUSPENSION:

Air Suspension a common method for coating solid or liquid core components with a polymeric or protective shell is air suspension microencapsulation. Using this technique, particles are suspended in an upward-moving air stream and then sprayed coating solution to create microcapsules. [18]

APPLICATIONS;

- **Pharmaceutical sector:**
  The pharmaceutical industry uses air suspension to improve the handling and stability of drug-containing microcapsules.
- **Food industry:** Air suspension is used in the food industry to enhance the stability and handling of microcapsules that contain flavourings or nutrients
- **Biotechnology;** Air suspension is used in biology to improve handling and stability

ADVANTAGES OF AIR SUSPENSION

1. **Improved Stability:** Air suspension can improvement the stability of substance

2. **Easy Handling:** Air suspension can make it easier to handle particles.
3. **Long-term Storage:** Air suspension can allow for long-term storage of particles. [19]

DISADVANTAGES OF AIR SUSPENSION

1. **Particle Aggregation:** Air suspension can cause substance to aggregate.
2. **Moisture Absorption:** Air suspension can expose particles to moisture.
3. **Oxidation:** Air suspension can expose small substance
4. **Static Electricity:** Air suspension can generate static electricity.
5. **Difficulty in Scaling Up:** Air suspension can be difficult to scale up. [19]

2. COACERVATION PHASE SEPARATION

Introduction

In this process, oppositely charged macromolecules, like proteins and polysaccharides, combine to produce a coacervate phase. The escalation mechanism. coacervation occurs when Macromolecules group together due to attraction. Coacervation is a phase separation process in which a homogeneous solution of macromolecules (such as proteins, polysaccharides, or synthetic polymers) separates into two liquid phases: a dense coacervate phase and a dilute supernatant phase. This process plays a crucial role in various biological and industrial applications, including drug Delivery encapsulation, and the formation of membrane less organelles in cells.

TYPES OF COACERVATION PHASE SEPARATION

1. **Simple Coacervation:** Occurs when a single polymer undergoes phase separate due to changes in solvent substance, temperature, or ph.
2. **Complex Coacervation:** Involves interactions between oppositely charged macromolecules, such as proteins and polysaccharides, leading to the formation of a coacervate phase.

APPLICATION OF COACERVATION PHASE SEPARATION

- **Food Industry:** Stabilised flavours and bioactive compounds.
- **Cosmetics:** Skin care cosmetic products' active material are enclosed.
- **Biotechnology;** is the process of creating synthetic membrane less organelles.

ADVANTAGES:

1. **High efficiency:** Coacervation phase separation has the potential to attain high separation efficiencies, often exceeding 90%.
2. **Scalability:** This process can be scaled up or down depending on the application, making it suitable for both laboratory and industrial settings
3. **Flexibility:** In order to attain the required purity of the separated phases, like washing or drying, can be required
4. **Mild conditions:** The process typically occurs under mild conditions, such as room temperature and atmospheric pressure, which helps preserve the integrity of the separated substance [20, 21]
5. **Low cost:** Coacervation phase separation can be a cost-effective method, especially when compared to other separation techniques like chromatography or crystallization.

DISADVANTAGES:

1. **Limited selectivity:** Coacervation phase separation may not always provide high selectivity, meaning that some impurities may remain in the separated phases.
2. **Sensitive to conditions:** The process can be sensitive to changes in temperature, pH, or ionic strength, which can affect the separation efficiency.
3. **Requires optimization:** Coacervation phase separation often requires optimization of the process conditions, such as the choice of solvents, surfactants, or other additives. [20,21]
4. **PAN COATING;** Pan coating is a microencapsulation method that involves spraying or pouring a liquid coating material onto a solid core material, such as a powder or particle, while it is being agitated or rotated in a pan.

STEPS INVOLVED IN PAN COATING MICROENCAPSULATION:

1. **Preparation of the core material:** The core material is prepared by sieving or milling to obtain a uniform particle size.
2. **Preparation of the coating material:** The coating material is prepared by dissolving or dispersing it in a suitable solvent
3. **Loading the core material into the pan:** The core material is loaded into the pan, which is typically a rotating drum or a vibrating pan.
4. **Spraying or pouring the coating material:** The coating material is sprayed or poured onto the core material while it is being agitated or rotated.
5. **Drying and curing:** The coated particles are dried and cured to form a stable microcapsule.

ADVANTAGES OF PAN COATING:

1. **High encapsulation efficiency:** Pan coating can achieve high encapsulation efficiencies, often above 90%.
2. **Uniform particle size:** Pan coating can produce microcapsules with a uniform particle size.
3. **A variety** of coating components, including as polymers, waxes, and fats, can be applied via pan coating.

DISADVANTAGE OF PAN COATING

1. **Labor-intensive:** The process of pan coating, which involves manually loading and unloading the pan, can be labor-intensive.
2. **Limited scalability:** Pan coating can be difficult to scale up to large production quantities.
3. **Coating material limitations:** Pan coating requires a coating material that can be easily sprayed or poured

PAN COATING APPLICATIONS:

1. **Pharmaceuticals:** Tablets and capsules containing pharmaceuticals product using pan coating.
2. **Food:** Food elements including tastes and minerals can be microencapsulated via pan coating.
3. **Cosmetics:** Skincare and haircare products are among the cosmetics are microencapsulation material

4. FLUIDIZED-BED TECHNOLOGY

The foundation of fluidized-bed technology is the fluidization principle, which states that a fluid should be pumped over a bed of solid particles quickly enough to cause the particles to suspend. One characteristic of the fluidized state is the creation of bubbles, which rise through the bed and carry solid particles with them. [22]

TYPES OF FLUIDIZED-BED REACTOR;

1. **1.Fluidized-bed reactors;** come in a variety of forms, such as: The most popular kind of fluidized-bed reactor is the bubbling reactor, in which the fluid is pumped through the bed
2. **Circulating fluidized-bed reactor:** In this type of reactor, the solid particles are circulated through the bed by the fluid, creating a high degree of mixing.
3. **Pneumatic conveying fluidized-bed reactor:** It is type of reactor uses a gas to convey the solid substance. [22]

ADVANTAGES OF FLUIDIZED-BED TECHNOLOGY

1. **1.High efficiency**: Fluidized-bed technology allows for high efficiency in mass transport, heat transmission, and mixing.
2. **2.Flexibility:** A variety of particle sizes and applications can be used using fluidized-bed technology.
3. **Minimal capital costs:** Fluidized-bed technology has minimal capital costs as compared to other technologies. [22]

APPLICATIONS OF PAN COATING

1. **Pharmaceutical industry:** For drying and granulating pharmaceutical powders;
2. **Cosmetic industry:** For chemical reactions compound and intensification of processes;
3. **Food industry:** it is drying and systematic process of food product [22]

SPRAY DRYING :

In the food, chemical, and pharmaceutical sectors, spray drying and spray congealing are common processes for turning liquid ingredients into powders or controlled-release particles. Although atomisation is a component of both approaches, their basic workings and uses are different.

APPLICATION OF SPRAY DRYING;

1. Utilizes cosmetic formulations (e.g., inhalable powders or drug encapsulation)
2. The food business (coffee, milk powder, flavouring, etc.)
3. Chemical manufacturing (detergents, pigments, etc.)

ADVANTAGE OF SPRAY DRYING ;

1. **Drawbacks** Improved solubility, uniform particle size, and rapid drying are among the advantages.
2. **Limitations**: it is Excessive energy consumption and heat-sensitive materials

6. MULTI-ORIFICE CENTRIFUGATION

Multi-orifice centrifugation is a technique that can be used to separate particles with varying densities and sizes. A fast-moving stream of air is produced by separating the particles in a centrifuge with several orifices.

Principles: The method uses the centrifugal force idea to separate the microscopic particles according to their density, size, and form. Centrifugal force, Relevant by the high-speed air stream Relevant by the several orifices, separates the material.

APPLICATION;

1. **1.Pharmaceutical industry;** The method used in the pharmaceutical industry to separate tiny particles with varying densities and sizes from powdered drugs and cosmetics Food powder is broken down into tiny fragments of varying sizes and densities in the food industry.
2. **Food industry:** separating food powder's tiny particles with varying densities

ADVANTAGES OF MULTI-ORIFICE CENTRIFUGATION;

1. Particles of different sizes and densities are separated by the process with high efficiency.
2. It technique is flexible enough to treat a wide range of material sizes and densities. **3.** Low maintenance: Cleaning and maintaining the method is easy.

DISADVANTAGES CENTRIFUGATION;

1. **Sample Damage:** Centrifugation can cause damage to the sample, especially if it is fragile or sensitive
2. **Complexity:** Specialised instruments and knowledge are required for the procedure.
3. **High energy consumption;** It is systemic operation required a significant amount of energy to generate the high-speed air stream. The technique may result in noise pollution due to the high-speed air stream.
4. **Limited Capacity:** Centrifuges typically have a limited capacity, which can make it difficult to process large samples or multiple samples at once.
5. **Requires Training and Expertise:** Centrifugation requires training and expertise to operate the centrifuge safely and effectively.
6. **Sample Loss:** Centrifugation can cause sample loss, especially if the sample is not properly secured in the centrifuge tube.
7. **period-Consuming Procedure:** Centrifugation can take a long period, particularly if several samples need to be processed.

BENEFITS OF CENTRIFUGATION;

1. **Efficient Separation:** Centrifugation allows for efficient separation of particles based on their density and size.
2. **High-Speed Processing:** Centrifugation enables high-speed processing of samples, making it an ideal method for large-scale separations.
3. **Versatility:** Centrifugation can be used to separate a wide range of particles, from cells and proteins to nanoparticles and contaminants.
4. **Improved Accuracy:** Centrifugation can improve the accuracy of separations by reducing the risk of human error and contamination.
5. **ncreased Productivity:** Centrifugation can increase productivity by enabling the simultaneous processing of multiple samples.
6. **Cost-Effective:** Compared to other techniques like chromatograph centrifugation is a significantly more economical way to separate particles.
7. **Time-Saving:** By automating the separation procedure and minimising the need for manual handling, centrifugation can save time and labour

Conclusion

Microencapsulation plays a crucial role in enhancing the efficiency of nucleic acid-based drug delivery by protecting therapeutic molecules from degradation, ensuring controlled release, and improving bioavailability. Various encapsulation techniques, including polymeric nanoparticles, liposomes, and hydrogels, have been explored to optimize drug stability and targeted delivery.
Microencapsulation is a valuable technology that enables the controlled release and protection of active ingredients in various fields such as pharmaceuticals, food, agriculture, and cosmetics.

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