Review Article

A Review of Current Trends in Microencapsulation Technology

Shruti Shrikant Takke*
A/p- SHEER, TAL- Guhagar, Dist- Ratnagiri, Maharashtra, India.
***Corresponding author's E-mail:** shrutitakke18@gmail.com

Received: 14-10-2025; **Revised:** 21-12-2025; **Accepted:** 28-12-2025; **Published online:** 20-01-2026.

ABSTRACT

Micro-encapsulation is advanced novel drug delivery technology that involves enclosing active pharmaceutical ingredients within polymeric coating to form micro-capsules capable of controlled, sustained and targeted release. This technique enhance therapeutic efficacy by improving drug stability, masking unpleasant taste or odour, protecting sensitive drugs from environmental degradation, and reducing adverse effects. Various methods, including co-acervation, spray drying, solvent evaporation, interfacial polymerization, and air- suspension coating, are employed depending on the drug and polymer characteristic. Microspheres, a key form of micro-encapsulation, further extend drug release and bioavailability, with application across pharmaceutical, agriculture, food, cosmetics, and textile. Current trend emphasize biodegradable polymer, stimuli- responsive "intelligent" capsules, and microfluidics - based system, with a global market projected to grow significantly by 2030. Marketed formulations such as Ritalin LA® (methylphenidate HCL) and Micro-K® Extencaps® (potassium chloride) highlight the clinical relevance and therapeutic advantages of this technology. Overall, microencapsulation remains a vital and expanding platform in the design of novel drug delivery system, promising greater precision, safety and efficacy in future therapeutics.

Keywords: Microencapsulation, Novel drug delivery, Polymeric coating, Controlled release, Sustained release, Therapeutic efficacy, Drug stability.

INTRODUCTION

The novel drug delivery is a new system, recent advances in our understanding of the pharmacokinetic and pharmacodynamic behaviour of drugs have made it possible to develop the best drug delivery system in a more rational way. Novel drug delivery systems (NDDS) are carriers that help maintain the drug concentration within the therapeutic range for prolonged periods of time. Novel drug delivery systems (NDDS) are better than conventional dosage forms because they combine state-of-the-art technology with creative dosage forms.[1]

Novel drug delivery systems (NDDS) are innovative approaches that combine new technologies, formulations, innovative development, and innovative methodologies to safely deliver pharmaceutical compounds in the body as needed to achieve their desired pharmacological effects. Controlled drug release and subsequent bio-degradation are necessary for the creation of effective formulations. Potential release mechanisms include the following: Drugs that are surface-bound or adsorbed can desorb; drugs can diffuse through the carrier matrix; drugs can diffuse through the carrier wall (in the case of nanocapsules); the carrier matrix can be eroded; and drugs can combine diffusion and erosion.[2]

In the pharmaceutical industry, novel drug delivery systems (NDDS) have become revolutionary tactics that aim to increase the efficiency, security, and convenience of medicine administration. Microencapsulation is one of the most promising NDDS technologies. It is a multidisciplinary approach that uses innovative development strategies, new technologies, and state-of-the-art formulations to safely and effectively achieve desired pharmacological effects.[3]

In order to improve a drug's therapeutic efficacy and reduce the problems associated with conventional therapy, a controlled drug delivery system has been employed. The optimal rate of delivery of the active agent to the target tissue can optimize therapeutic efficacy while reducing toxicity and side effects.[4]

Micro-encapsulation is the process by which individual particles or droplets of solid or liquid material (the core) are surrounded or coated with a continuous film of polymeric material (the shell) to produce capsules in the micrometer to millimeter range, known as micro-capsules. Micro-capsules depends mainly on the core material and the deposition process of the shell.[5]

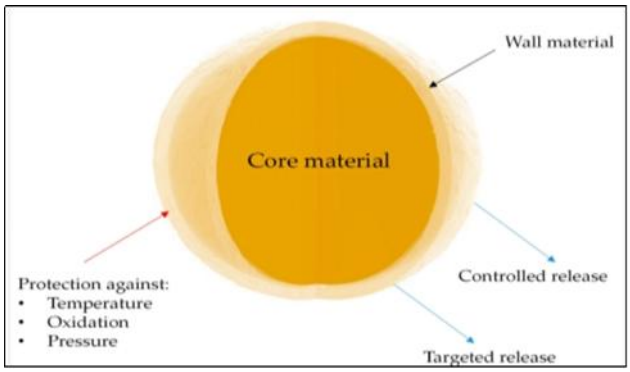


Figure 1: Core material

Transforming liquids into solids, altering surface and colloidal properties, protecting the environment, and controlling the release properties or availability of coated materials are all possible with micro-encapsulation.[6]

Bungenburg de Jon & Kan first described the micro-encapsulation process in 1931.[7]

The objective is to provide an overview of the latest developments in API micro-encapsulation, which can improve bio-availability, control release, target delivery, and mask bitter taste and stability in order to increase efficacy and decrease side effects.[8] Micro-encapsulation allows for the modification of the encapsulated material's like, colour, shape, apparent density, volume, durability, reactivity, heat sensitivity, pressure sensitivity, and photo-sensitivity.[9]

Potential applications and benefits of micro-encapsulation in the pharmaceutical sector include the following:

- Therapeutic efficacy is increased and side effects are decreased when the intended site is targeted.
- Controlling the drug's release from encapsulated micro-particles.
- By establishing a barrier between the drug and its environment, drug stability is improved.
- Reduce Particle size increases the solubility of poorly soluble drug.[10]
- A few tenths of an um to several thousand um is the range of sizes for microcapsule particles.[11]

The ability of micro-encapsulation technology to shield the active ingredients from potentially harmful conditions such as oxidation, heat, acidity, alkalinity, moisture, or evaporation.[12] The chemical industry, biology engineering, and pharmaceutical manufacturing have all made extensive use of micro-encapsulation technology. The suspension is known as micro-encapsulated phase change material slurry (MPCS) because it is made up of micro-capsules with phase change material as the core material mixed with a carrier fluid.[13]

REASONS OF MICROENCAPSULATION

To protect vitamins from the harmful effects of oxygen, delay the evaporation of a volatile core, improve the handling properties of a sticky substance, or protect a reactive core from chemical attack, for example, the core must be isolated from its surroundings.[14]

1. The primary goal of microencapsulation is to provide a medication with delayed or sustained release.
2. Using microencapsulation has also been used to alter the absorption site. For medications whose toxicity increases with decreasing pH, this application has been helpful.[15]
3. masking of the encapsulated materials' activity, taste, and odour.
4. Distinguishing of incompatible parts.[16]
5. allowing materials to be released controlled and/or sustained control.
6. It is possible to turn liquid medicine into a freely flowing powder.[17]
7. Additionally, microencapsulation helps to avoid drug incompatibilities and the vaporization of volatile medications such as peppermint oil and methyl salicylate.[10]

ADVANTAGE OF MICROENCAPSULATION

1. Extended shelf life as a result of inhibition of degradation reactions.
2. The masking of odour and bitter taste.[18]
3. Protecting the core materials or encapsulated active agents from the elements.
4. Liquids and gases can be turned into solid particles using microcapsules.
5. Modify and delay the release of medications in different pharmaceutical dosage forms.
6. Sustained controlled release dosage forms can be produced by modifying or delaying the release of encapsulated active agents or core materials.[19]
7. For reducing the gastrointestinal distress, numerous medications have been microencapsulated.[20]

DISADVANTAGE OF MICROENCAPSULATION

1. The materials and formulation process may be more expensive than for standard formulations.
2. Reproducibility is reduced.
3. The polymer matrix, polymer additives, and their breakdown products have a variety of environmental effects when they are exposed to heat, hydrolysis, or biological agents.
4. The stability of the core particle is affected by modifications to process variables like temperature, PH, solvent addition, or solvent evaporation.[21]

MICROSPHERE

Micro-spheres are free-flowing powders made of synthetic polymers or proteins that are biodegradable and ideally have a particle size of less than 200 µm.[22]

The following criteria should be fulfilled by micro-spheres:

1. Microspheres should be able to transport a significant amount of the drug.
2. They must be stable and have a reasonable shelf life.
3. They should have a controlled size and dissolve well in water for injection.
4. The drug should be taken under supervision and gradually.[23]

Typically, polymers are used as microspheres. They can be divided into two groups are as follows:

Table 1: Types of polymer

Natural polymer	Protein	Gelatin, Collagen, Albumin
	Carbohydrate	Starch, Agarose, Carrageenans
	Chemically Modified Carbohydrate	Poly acryl Starch, Poly acryl Dexron[24]
Synthetic Polymers	Non-biodegradable	Glycidyl methacrylate, Epoxy polymers, Acrolein, etc.
	Biodegradable	Polyanhydrides, Polyalkylcyano- acryalates Lactides glycosides, and their copolymers[25]

TYPES OF MICROSPHERES

I. **Bioadhesive microspheres**: The drug's ability to adhere to a membrane using this property can be described Water-soluble polymer adhesion. This kind of microsphere has a long residence period at the application site. For example, the drug delivery device's adherence to the nasal, buccal, ocular, and rectal mucosal membranes.[26]

II. **Magnetic microspheres**: These are ferromagnetic molecules, which means they are extremely sensitive to being trapped in micro-vessels and drawn through surrounding tissues by a magnetic field of 0.5–0.8 tesla. They are small enough to pass through capillaries without obstructing the esophagus (less than 4 µm). Magnetic microspheres are essential for locating the medication at the site of the disease.

- Therapeutic magnetic microspheres
- Diagnostic microspheres[27]

III. **Floating microspheres**: These drug delivery systems are gastroretentive due to their non-effervescent design. Hollow microspheres, floating microparticles, and microballoons are other names for floating microspheres. To put it simply, floating microspheres are small, hollow, centerless objects that are between 1 and 1000 µm in size. These cells are move freely.[28]

IV. **Polymers**:

a. **Biodegradable polymeric microspheres**: Due to their biodegradability, biocompatibility, and bioadhesiveness, natural polymers such as starch are utilized. Biodegradable polymers gel and stay in contact with mucous membranes for long periods of time due to their high degree of swelling in aqueous media. The rate and extent of drug release are controlled by the polymer concentration and the release pattern over time.[25]

b. **Synthetic polymeric microspheres**: Synthetic polymeric microspheres have shown themselves to be safe and biocompatible and are utilized extensively in clinical applications as well as bulking agents, fillers, embolic particles, and drug delivery vehicles. However, the primary drawback of these microspheres is their propensity to disperse from the injection site, which increases the risk of embolism and additional organ damage.[29]

MICROCAPSULE

Tiny spheres with a uniform wall around them are called micro-capsules. The material inside the microcapsule is referred to as the core or internal phase, whereas the wall is occasionally called a shell or coating.[30]

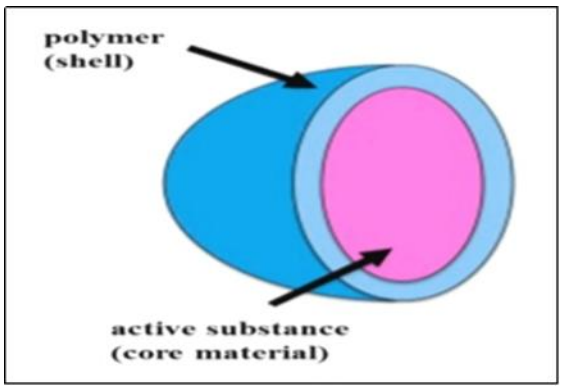
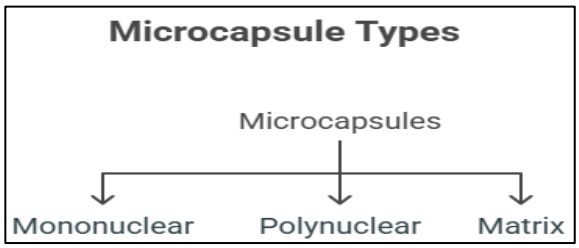


Figure 2: Microcapsule

TYPES OF MICROCAPSULES



1. **Mononuclear**: In mononuclear (core–shell) microcapsules, the shell encloses core.
2. **Polynuclear**: Many cores are enclosed by the shell of poly-nuclear capsules.
3. **Matrix**: In which the core material are evenly distributed into shell material.[31]

MATERIAL USED FOR MICROENCAPSULATION

1. **Core Material**: The core material, which is the particular substance that will be coated, can be either liquid or solid and contain one or more medications either by themselves or in combination with appropriate additives to create a liquid or solid phase. While solid core is made up of active ingredients, stabilizers, diluents, excipients, and release-rate retardants or accelerators, liquid core can be made up of polar or non-polar substances and may contain dissolved and/or dispersed materials.[32]

2. **Coating Material**: The protective layer that envelops the core is made up of the shell material, sometimes referred to as the wall material or coating material. Depending on the required release properties and compatibility with the core material, a variety of natural and

synthetic polymers, including proteins, polysaccharides, and biodegradable polymers, can be used as shell materials. [3]

Characteristics of coating materials:

i. Core material stabilization.

ii. Insensitive to the active components.

iii. Limited release under specific condition.

iv. Stable, tasteless, pilable, and film-forming.

v. Economical, low viscosity, and non-hygroscopic.

vi. Covalent or soluble in an aqueous media.

vii. The coating may be thin, hard, brittle, flexible, etc.[4]

EXAMPLES OF COATING MATERIAL

- Water soluble resin: Polyvinyl alcohol (PVA), Modified coating starch and Carboxymethyl cellulose (CMC).[33]
- Water insoluble resin: Cellulose nitrate, Silicones, Poly lactideco glycolide, Ethylcellulose, Polyethylene, Polymethacrylate, Polyamide (Nylon), Poly (Ethylene Vinyl acetate).[34]
- Waxes and Lipids: Carnauba, Spermaceti, Paraffin, Stearic acid, Stearyl alcohol, Glyceryl stearate, Bees wax.
- Enteric Resin: Cellulose acetate phtalate, Zein, Shellac.[35]

MECHANISM AND KINETICS DRUG RELEASE

Drug release from microcapsules occurs primarily through four processes: diffusion, osmosis, dissolution, and erosion.

1) **Diffusion**: The most often used mechanism is diffusion, in which the dissolving fluid enters the shell, dissolves the core, and then leaks out through the pores or interstitial channels. Therefore, three factors determine the total release: (a) the rate at which the dissolution fluid enters the microcapsule wall; (b) the rate at which the drug dissolves in the dissolution fluid; and (c) the rate at which the dissolved drug leaks out and disperses from the surface. Such drug release kinetics follow Higuchi's equation as shown below.

$$Q = [D/J (2A- \varepsilon CS) CS t] ½$$

Where, Q is the amount of drug released per unit area of exposed surface in time t.

A is the total amount of drug per unit volume,

D is the solute's diffusion coefficient in the solution

J is the tortuosity of the capillary system in the wall

CS is the drug's solubility in the permeating dissolution fluid

ε is the microcapsule wall's porosity.

$$Q = vt,$$

Where, v is the apparent release rate, is a simplified version of the equation above.[36]

Dissolution: When the polymer coat is soluble in the dissolution fluid, the rate at which the drug is released is determined by the rate at which the coat dissolves. It also depends on the coat material's thickness and solubility in the dissolving fluid. Either the capsule wall melts or the coat dissolves, releasing the medication. Dissolution is the rate at which the drug is released is directed by the rate at which the polymer coat dissolves when it is soluble in the dissolution fluid. The thickness and solubility of the coat material in the dissolving fluid also play a role. The drug is released when the coat dissolves or the capsule wall melts.[37]

Osmosis: Through microscopic holes in the polymer coat, which serves as a semi-permeable membrane and allows for the creation of an osmotic pressure differential between the microcapsule's interior and exterior, drug solution is forced out of the microcapsule.[38]

Erosion: The pH or enzymatic hydrolysis of the coat causes the drug to be released through an erosion mechanism. Microcapsule drug release has grown more complicated. Microcapsules differ in their size, shape, and the way their core and coat materials are arranged. Core material physico-chemical characteristics, such as solubility, diffusibility, partition coefficient, and for coating material types Resin soluble in water properties of water-insoluble resin coatings, such as porosity and thickness. Microcapsules release a fixed amount of drug over a predetermined period of time, following zero order kinetics, which means that the release rate is constant. The first half of the total drug release from monolithic microcapsules is t½ dependent, and then it decreases exponentially. [39]

MICROENCAPSULATION TECHNIQUE

Air Suspension Technique

Phase Separation Coacervation

Spray Drying and Spray Congealing

Solvent Evaporation

Multi-Orifice Centrifugal Process

Pan Coating

Interfacial Polymerization

1) AIR SUSPENSION METHOD

Another name for the air suspension method is the "Wurster process." It is simultaneously spraying coating, where the particles are suspended and dispersing the solid, particulate core material in a supporting air stream. [40]As the moving particles repeatedly pass through the coating zone, the core material receives more coating material. Depending on the required coating thickness or whether the core material particles are completely encapsulated, this cyclic process is repeated approximately 100 times. The product that is encapsulated is allowed to air dry.[41]

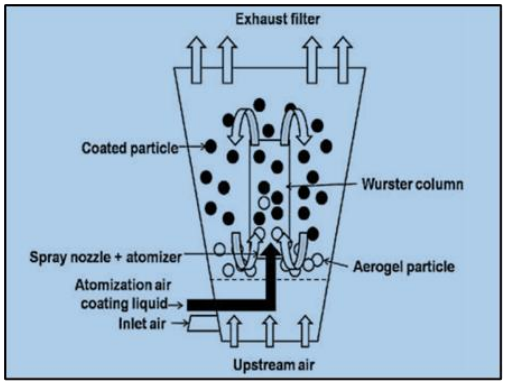


Figure 3: Air Suspension

ADVANTAGES

- Increased Stability: Air suspension can increase a substance's stability.
- Simple Handling: Particle handling may be facilitated by air suspension.
- Long-term Storage: Particles may be stored for an extended period of time in air suspension. [42]

DISADVANTAGES

- only applicable to solids.
- A high degree of proficiency is required.
- There may be solid agglomeration.[43]

2) PHASE SEPARATION COASERVATION METHOD

Coacervation also referred to as "phase separation" is regarded as a true microencapsulation technique, Since the matrix are completely entrapped by the core material. In coacervation, a liquid coating material phase is separated from a polymeric solution, and then it is coated as a homogeneous layer around suspended core particles.[44]

Three steps are typically involved in coacervation-phase separation microencapsulation, which is carried out with constant agitation:

A. The development of three chemical phases that are incompatible,

B. Deposition of coating,

C. Rigidization of the coating material.[45]

A. **The development of three chemical phases that are incompatible**

i. **Thermal Change**: A weighed quantity of ethyl cellulose was dissloved in cyclohexane and heated at 80^{0}C while being vigorously stirred in cyclohexane. The drug was then finely ground and vigorously stirred into the above solution. Phase separation was achieved by lowering the temperature with an ice bath, washing twice with cyclohexane, letting it air dry, and then passing it through a sieve (sieve no. 40) to produce individual microcapsules 25.[46]

ii. **Addition of incompatible polymers**: It can be achieved by using the incompatibility of dissimilar polymers present in a common solvent to achieve microencapsulation and liquid phase separation of a polymer coating material.[47]

iii. **Addition of non-solvent**: After a weighed amount of ethyl cellulose was dissolved in toluene containing propyl-isobutylene, the drug was dispersed in a closed beaker with magnetic stirring for six hours at 500 rpm as part of the coacervation non solvent addition procedure. After that, the stirring lasted for another fifteen minutes. The microcapsules were cleaned with n-hexane, allowed to air dry for two hours, and then baked for four hours at 50 degrees Celsius after five rounds of petroleum benzoin phase separation with continuous stirring.[29]

B. **Deposition of coating**: Applying a liquid polymer coating to the core material is known as coating deposition. This is achieved by carefully mixing the liquid coating material with the core material in the manufacturing vehicle. The liquid coating polymer is deposited on the core material if the polymer is adsorbed at the interface that develops between the liquid phase and the core material. The overall free inter-facial energy of the system decreases as a result of the coating material's surface area decreasing during the coalescence of the liquid polymer droplets, which facilitates the coating material's deposition.[48]

C. **Rigidization of coating material**: Thermal, cross-linking, or desolvation methods are commonly used to make the coating rigid in order to form a microcapsule.[49]

3) **Spray drying and spray congealing**

Spray drying and spray congealing are similar processes because they both entail dispersing the core material in a liquefied coating substance and then spraying or introducing the core coating mixture into an environment that affects the coating's comparatively rapid solidification. Coating solidification is where the two approaches diverge most. While spray congealing is achieved by thermally congealing a molten coating material or by solidifying a dissolved coating by introducing the coating core material mixture into a nonsolvent, spray drying relies on the quick evaporation of a solvent in which the coating material is dissolved to achieve coating solidification.[46]

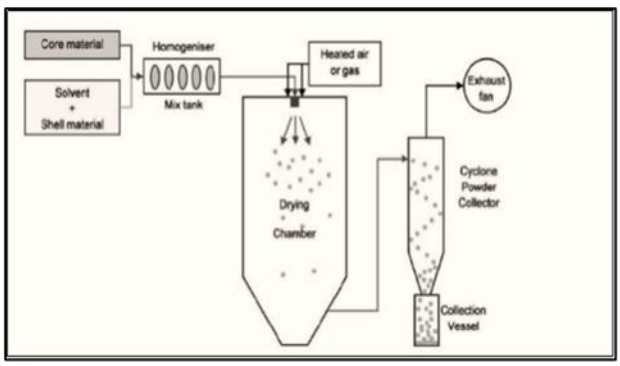


Figure 4: Spray drying and spray congealing

First, the polymer is dissolved in an appropriate volatile organic solvent, like acetone, dichloromethane, etc. A stream of hot air is then used to atomize the solid drug after

it has been dispersed in the polymer solution under high-speed homogenization. The atomization process creates tiny droplets or a fine mist, from which the solvent instantly evaporates to form microspheres that range in size from 1 to 100 µm.[50]

4) **Solvent evaporation**

A coating polymer solution is first made by dissolving the coating polymer material in a volatile solvent that is immiscible in an LMV (Liquid Manufacturing Vehicle). The core material is then either dissolved or dispersed in the coating polymer solution, depending on how hydrophobic or hydrophilic it is. The mixture is then added to the LMV phase while being continuously stirred until the solvent separates into the aqueous phase and evaporates. Here, the core material is surrounded by shrinking coat material, creating hardened microspheres.[51]

5) **Multi-orifice Centrifugal process**

Mechanical microencapsulation is a method of creating microcapsules that uses centrifugal forces and a core material particle through an enveloping microencapsulation membrane therapy. This technique can microencapsulate liquids and solids of different sizes with a variety of coating materials. Processing variables include the cylinder's rotational speed, the flow rate of the core and coating materials, the coating material's concentration and viscosity, and the core material's viscosity and surface tension.[47]

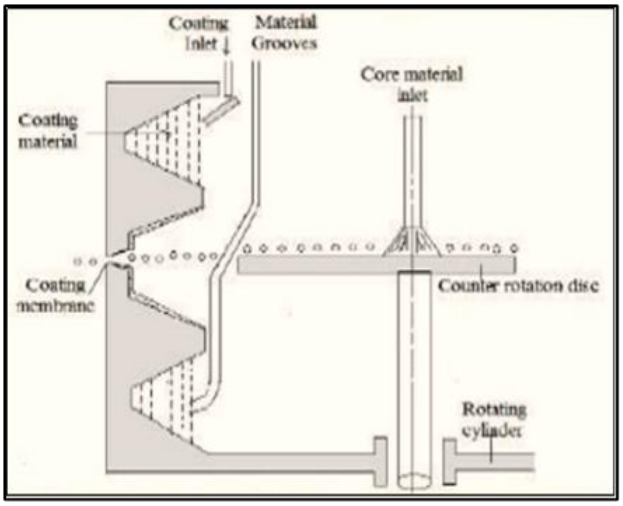


Figure 5: Multi-orifice Centrifugal process

6) PAN COATING

As the particles tumble in a rotating pan or other device, the coating material is applied gradually at a controlled temperature profile.[13] The coating is applied as an atomized spray or as an a solution to the desired solid core material in the coating pans, warm air is passed over the coated materials to remove the coating solvent. The final solvent removal is completed in a drying oven.[22]

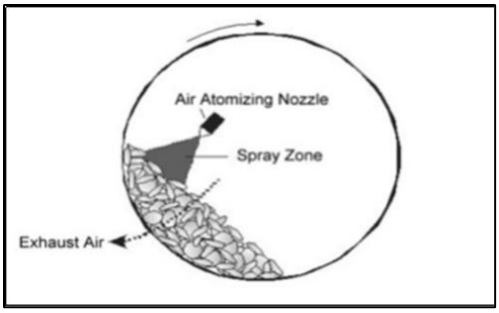


Figure 6: Pan Coating

ADVANTAGE

- It's easy to release the product.
- Used to apply a syrup coating.
- Utilized with CR-formulated beads.
- Simple and direct approach.
- Whether hot or cold air is used depends on properties of the fundamental components.[53]

DISADVANTAGE

- The core material will adhere.
- Comparing a substantial coating layer to an alternative strategy[53]

7) INTERFACIAL POLYMERIZATION

In order to create a polymer film that effectively envelops the dispersed phase, different monomers react at the interface between the two immiscible liquid phases.

Two reactive monomers are involved in the interfacial polymerization process; one is dissolved in the continuous phase, and the other is distributed there. During the continuous phase, which is frequently aqueous, the second monomer is emulsified. At the interface, the monomers rapidly diffuse and polymerize. The carrier form may change based on the polymer's solubility in the emulsion droplet. Polymerization can be influenced by temperature, reactivity, vehicle composition, and monomer concentration. The size of globules or droplets in the dispersed phase can be changed to control the size of the particles. Maintaining a constant monomer concentration is necessary to regulate the polymerization process.[54]

APPLICATION

1) To mask the bitter taste of medications such as nitrofurantoin and paracetamol.

2) To reduce the gastrointestinal distress and irritations, numerous medications have been microencapsulated. additional G.I. tract Compared to conventional preparations, sustained release aspirin preparations have been shown to cause noticeably less gastrointestinal bleeding.[14]

3) To facilitate handling and storage, a liquid can be transformed into a pseudo-solid. For example, Eprazinone.

4) Microencapsulation may lessen the hygroscopic characteristics of the core material. For example, sodium chloride.

5) To lessen their volatility and odour, carbon tetra chlorides and several other substances have been microencapsulated.

6) Microencapsulation has been used to shield the core materials from the effects of the atmosphere. For example, Vitamin A palmitate.

7) Encapsulation has been used to separate incompatible substances.[34]

8) Cosmetics:

Better skin penetration: Active ingredients can enter the skin more easily thanks to microencapsulation, which increases their efficiency.

Improved moisturization: Microencapsulation is used to improve skin hydration and comfort by increasing skin moisturization.

Less irritation: The application of microencapsulation lessens the irritation brought on by active ingredients, enhancing the comfort and safety of the skin.[42]

9) Textile: Phase-change materials: These materials undergo a phase-change from solid to liquid aggregation within a particular temperature range. This keeps the temperature constant and facilitates the thermoregulation of clothing. Numerous textiles, such as blankets, mattresses, parkas, snowsuits, vests, and more, are coated with these microcapsules.[55]

10) In Vaccine Delivery: Microcapsules have been employed as carriers in vaccine delivery because they control and stabilize the release of antigens. The medication increases patient convenience by reducing the need for multiple doses. Leuprolide acetate, an analog of gonadotropin-releasing hormone, is found in the core and is used to treat endometriosis, breast cancer, and prostate cancer.[39]

CURRENT TRENDS IN MICROENCAPSULATION TECHNOLOGY

It is anticipated that the global microencapsulation market, valued at US$16.626 billion in 2025, will grow at a compound annual growth rate (CAGR) of 6.83% to reach US$23.131 billion by 2030. Microencapsulation technology is crucial in industries such as food, agrochemicals, cosmetics, and pharmaceuticals because it coats an active compound with an encapsulating agent. Microencapsulation improves product stability in the food industry by lowering reactivity, volatility, and unfavourable smells. It modifies drug release, improves drug stability, lessens the reactivity of key ingredients, and covers up the taste and smell of some medications.[56]

The goal of advancements in hepatocyte transplantation encapsulation material is to enhance immune protection, cell survival, and function. Success depends on a number of variables, including the implantation site, which affects immunological, nutritional, and oxygen responses, and cell dose, where a sufficient number of hepatocytes are required for the therapeutic effect without causing complications. Encapsulation functions mechanically by forming a barrier (such as alginate) that protects hepatocytes from immune assault while allowing the exchange of nutrients and metabolites. By providing trophic support and a favourable microenvironment, co-encapsulation with supportive cells, such as messenchymal stem cells, can further improve hepatocyte viability and liver-specific functions.[57]

A promising technology for functional foods is microencapsulation, which preserves bioactive ingredients such as probiotics and prebiotics, increases their stability, and allows for controlled release in the body. Further research, especially in the field of co-encapsulation, is needed to enhance nutrition, promote gut health, prevent disease, and meet the increasing demand for healthier foods and beverages.[58]

The latest developments in microencapsulation technology is,

1.Biodegradable and biobased encapsulating materials.

2.Intelligent pills that release in response to stimuli.

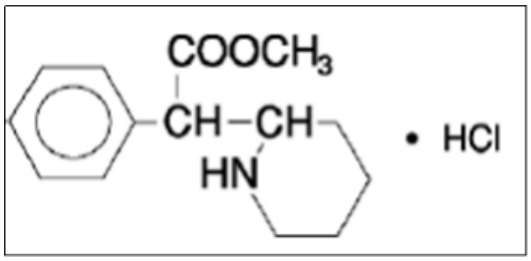
3.Multilayer capsules for improved performance.

4.Techniques for encapsulation based on microfluidics for improved effectiveness.

Incorporating nanotechnology to achieve better results.[59]

MARKETED PRODUCT

1. **Ritalin LA®**: Ritalin LA® (methylphenidate hydrochloride) is acts on the central nervous system (CNS). The extended-release methylphenidate formulation Ritalin LA® (methylphenidate hydrochloride) capsules has a bi-modal release profile. A methylphenidate immediate release and a second delayed release are provided by the half-dose of immediate-release beads and the other half of enteric-coated, delayed-release beads found in each Ritalin LA capsule filled with beads. Ritalin LA's active ingredient, methyl α-phenyl-2-piperidineacetate hydrochloride, has the structural formula,



Methylphenidate hydrochloride USP is a finely crystalline, white, odourless powder. Acid to litmus are its solutions. It dissolves readily in methanol, water, alcohol, and is slightly soluble in acetone and chloroform has molecular weight is 269.77.[60]

❖ **Mechanism of Action of Methylphenidate**

- Neurotransmitter Regulation: By preventing their reuptake, methylphenidate influences the brain's dopamine and norepinephrine levels.
- Enhanced Dopamine Activity: Ritalin improves mood and concentration by blocking dopamine reuptake, which makes more of this neurotransmitter available in synaptic clefts.
- Modulation of Norepinephrine: The drug also affects norepinephrine, which improves focus and alertness.[61]

❖ **Uses:** ADHD (Attention Deficit Hypersensitivity Disorder) Children with ADHD have shown a clear improvement in their outcomes when taking Ritalin. Ritalin helps children focus better and pay attention for longer periods of time and reduces hyperactivity. Ritalin therapy also works well for adults with ADHD. In Ritalin facilitates their ability to focus and stay on task, enhance their attention span, and reduce hyperactivity. [62]

❖ **Side Effects**: Hallucination, Headache, Stomach pain, Nervousness, Dry mouth, Constipation, Skin rash.[61]

2. **Micro-K® Extencaps® Capsules**: Potassium chloride (KCl) is made dispersible by using a dispersing agent and microencapsulation. The flow characteristics of the resulting KCl microcapsules and the controlled release of K^+ ions from the microcapsular membrane are designed to ensure that excessive KCl cannot be localized at any location on the mucosa of the gastrointestinal tract. Using a patented process, each KCl crystal is microencapsulated with an insoluble polymeric coating that acts as a semi-permeable membrane, allowing potassium and chloride ions to be released gradually over the course of eight to ten hours. The potassium chloride solution that is produced gradually permeates the membrane and spreads outward. Micro-K® and Micro-K® 10 are supplemented with electrolytes. Potassium chloride is the active ingredient's chemical name, and its structural formula is KCl. Potassium chloride, USP, can be found as colourless crystals or as a white, granular powder. It has saline taste and no smell. Litmus has no effect on its solutions. It is insoluble in alcohol and readily soluble in water.[63]

- **Mechanism of action:** Potassium ions participate in a number of physiological processes including the maintenance of intracellular tonicity; the transmission of nerve impulses; the contraction of cardiac, skeletal and smooth muscle; and the maintenance of normal renal function. Depletion may occur whenever the rate of potassium loss through renal excretion and/or loss from the gastrointestinal tract exceeds the rate of potassium intake.[64]

❖ **Side effects:**

1) Appearance of a potassium chloride tablet in your stool
2) Gas
3) Diarrhoea
4) Tingling in your hands or feet
5) Nausea
6) Vomiting
7) Upset stomach[65]

❖ **Uses:** Drug-induced hypokalemia, liver cirrhosis, cholera, vomiting, weak muscles, paralysis, cardiac and congestive heart failure, diabetic ketoacidosis, ulcerative colitis, weakness, anorexia, drowsiness, Cushing's syndrome, pyloric stenosis, and low blood pressure.[66]

CONCLUSION

Microencapsulation has emerged as one of the most versatile and transformative technologies in novel drug delivery system (NDDS), offering controlled release, targeted delivery, improved bioavailability and enhanced patient compliance. By enclosing active agents within protective polymeric coatings, this technology addresses key challenges of conventional therapy- such as poor solubility, instability, rapid degradation and undesirable taste or odour- while enabling sustained and site- specific release. Various encapsulation methods, including coacervation, spray drying, solvent evaporation and interfacial polymerization, provide flexibility in tailoring formulations to different therapeutics and industrial applications. Beyond pharmaceuticals, microencapsulation has demonstrated immense utility in food technology, agriculture, cosmetics and textiles, reflecting its multidisciplinary significance.

Current trends, including biodegradable polymer coatings, stimuli- responsive “Smart” Capsules, microfluidics- based encapsulation, and integration with nanotechnology, highlight the evolving potential of this fields. Marketed products such as Ritalin LA® and Micro-K® successfully illustrate its clinical impact in enhancing therapeutics effectiveness while minimizing side effects with strong growth expected in the global microencapsulation market, ongoing research promises even more precise, sustainable, and patient- friendly drug delivery options. Ultimately, microencapsulation stands as a cornerstone in advancing modern therapeutics and cross-industry innovation, bridging science and technology to meet growing healthcare and industrial needs.

Source of Support: The author(s) received no financial support for the research, authorship, and/or publication of this article

Conflict of Interest: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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