A Comparative Study of Encapsulation Technologies for Controlled Release of Fragrance Compounds

Vishal D. Deshmukh (Chief Perfumer), Vaibhav Agrawal (CEO & Managing Director)

Affiliation

Norex Flavours Pvt Ltd-Dhanaura, U.P., India-244231

Email: vdeshmukh@norex.in, vaibhav@norex.in

ABSTRACT

Fragrance performance is a critical determinant of consumer acceptance in personal care, home care, and fabric care products; however, the inherent volatility and chemical instability of fragrance compounds often result in significant losses during formulation, processing, storage, and end use. Encapsulation technologies have therefore gained increasing importance as effective strategies to protect fragrance ingredients and enable controlled and sustained release. This study presents a comparative evaluation of key encapsulation techniques employed in fragrance formulation, including spray drying, complex coacervation, polymeric microencapsulation, cyclodextrin inclusion complexation, and nanoencapsulation systems. The fundamental principles, encapsulating materials, release mechanisms, performance characteristics, advantages, and limitations of each technique are systematically analyzed. Furthermore, industrial applicability is assessed with respect to product format, desired release profile, cost efficiency, and regulatory considerations. The comparative insights provided in this study aim to assist formulators and researchers in selecting suitable encapsulation technologies for achieving enhanced fragrance stability, controlled release behavior, and improved overall product performance.

KEYWORDS: Fragrance encapsulation; Controlled release; Microencapsulation; Nanoencapsulation; Spray drying; Cyclodextrin inclusion complexes; Polymeric microcapsules; Consumer product formulations

1. INTRODUCTION

Fragrances serve as critical functional components in consumer products, contributing significantly to sensory perception, brand differentiation, and overall product acceptance. However, many fragrance compounds exhibit high volatility and chemical sensitivity, making them prone to degradation through oxidation, hydrolysis, and interactions with formulation ingredients such as surfactants, solvents, and packaging materials. These factors often lead to diminished fragrance intensity, reduced stability during storage, and limited longevity on application substrates including skin, textiles, and hard surfaces.

To address these challenges, encapsulation technologies have emerged as effective approaches for protecting fragrance ingredients and enhancing their performance. Encapsulation involves the entrapment of fragrance oils within carrier materials that act as physical and chemical barriers, thereby reducing premature evaporation, minimizing degradation, and masking undesirable olfactory notes. Moreover, encapsulated systems enable controlled and targeted fragrance release in response to external stimuli such as mechanical stress, moisture, temperature variations, or pH changes.

With the growing demand for long-lasting, stable, and cost-efficient fragrance solutions in personal care, home care, and fabric care products, the selection of suitable encapsulation technology has become an integral aspect of modern fragrance formulation. This study presents a comparative evaluation of commonly employed fragrance encapsulation techniques, with emphasis on their underlying mechanisms, release behavior, performance attributes, and industrial applicability.

2. PRINCIPLES OF FRAGRANCE ENCAPSULATION & CONTROLLED RELEASE

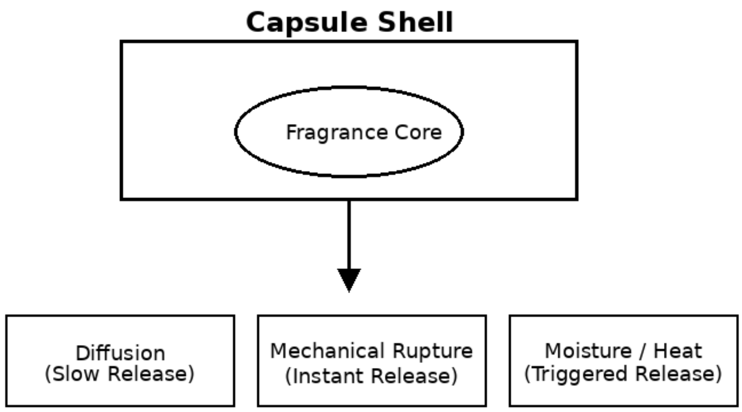
Fragrance encapsulation is a formulation strategy in which volatile fragrance compounds are physically entrapped or chemically incorporated within a protective carrier system, resulting in micro- or nano-sized encapsulated structures. An encapsulated fragrance system typically comprises a **core material**, consisting of single or multiple fragrance components, and a surrounding **shell or matrix**, formed from natural or synthetic encapsulating materials. The primary objective of encapsulation is to isolate fragrance compounds from adverse environmental and formulation conditions while enabling controlled and targeted release during product use.

The effectiveness of fragrance encapsulation depends on several factors, including capsule morphology, particle size distribution, shell composition, core-to-shell ratio, and the interaction between the encapsulating material and the fragrance molecules. These parameters directly influence fragrance retention, release kinetics, and overall sensory perception.

2.1 Mechanisms of Controlled Fragrance Release

Controlled release from encapsulated fragrance systems can occur through one or more of the following mechanisms:

Figure 1. Controlled release mechanisms of encapsulated fragrances



The release behaviour depends on shell material properties, capsule size, and external stimuli, enabling tailored fragrance performance.

2.1.1 Diffusion-Controlled Release

In diffusion-controlled systems, fragrance molecules gradually migrate from the capsule core through the shell or matrix into the surrounding environment. This process is governed by concentration gradients, shell porosity, and the permeability of the encapsulating material. Such systems typically provide a slow and sustained release profile and are commonly observed in spray-dried particles, cyclodextrin inclusion complexes, and polymeric matrix systems. Diffusion-controlled release is particularly advantageous for maintaining low-level background fragrance over extended periods.

2.1.2 Mechanically Triggered Release

Mechanical rupture occurs when external forces such as rubbing, washing, squeezing, or wearing exert sufficient stress on the capsule wall, causing it to break and release the encapsulated fragrance. This mechanism is characteristic of polymeric microcapsules and complex coacervate systems with well-defined shell structures. Mechanically triggered release enables an intense fragrance burst at the point of use and is widely utilized in fabric care and personal care applications where tactile interaction is expected.

2.1.3 Environmentally Responsive Release

Environmental stimuli such as moisture, temperature, and pH can influence the integrity or solubility of encapsulating materials, leading to fragrance release. Moisture-sensitive systems release fragrance upon exposure to humidity or water, making them suitable for laundry and bathroom applications. Thermally responsive systems release fragrance at elevated temperatures, while pH-sensitive encapsulation systems are designed to respond to specific pH conditions encountered during product use. These smart release mechanisms allow for targeted fragrance delivery under predefined conditions.

2.1.4 Degradation-Controlled Release

In degradation-controlled systems, fragrance release occurs as a result of gradual chemical or enzymatic breakdown of the encapsulating material over time. Biodegradable polymers and natural biopolymers are commonly used in such systems to achieve sustained fragrance release while addressing environmental and regulatory concerns. This mechanism provides long-term release and is increasingly relevant in the development of sustainable fragrance delivery systems.

2.2 Factors Influencing Encapsulation Performance

The selection of encapsulation technology significantly impacts fragrance stability, release behavior, and sensory performance. Key influencing factors include capsule size and surface area, shell thickness and composition, encapsulation efficiency, and compatibility with the formulation matrix. Additionally, processing conditions and storage environments play critical roles in determining the long-term performance of encapsulated fragrance systems.

A comprehensive understanding of these principles is essential for selecting appropriate encapsulation strategies tailored to specific product applications and desired fragrance performance outcomes.

3. MAJOR ENCAPSULATION TECHNOLOGIES USED IN FRAGRANCE FORMULATION

Encapsulation technologies employed in fragrance formulation vary widely in terms of materials, processing methods, capsule morphology, and release behavior. The selection of an appropriate encapsulation technique is primarily governed by the intended product application, desired fragrance release profile, formulation compatibility, and economic feasibility. The major encapsulation technologies commonly used in the fragrance industry are discussed below.

3.1 Spray Drying

Spray drying is among the most extensively utilized encapsulation techniques in the fragrance and flavor industries due to its operational simplicity, scalability, and cost efficiency. In this process, fragrance oil is first emulsified in an aqueous solution containing wall materials such as modified starches, maltodextrins, gum arabic, or cellulose derivatives. The emulsion is then atomized into a hot drying chamber, where rapid evaporation of water results in the formation of dry, free-flowing microcapsules.

The resulting spray-dried particles typically exhibit a matrix-type structure, in which fragrance molecules are dispersed within the solid carrier. Fragrance release primarily occurs through diffusion, although partial release may also take place due to surface-deposited fragrance.

Figure 2. Schematic representation of spray drying based fragrance encapsulation

Fragrance Oil+Wall material+Water

↓ **(Emulsification)**

Stable O/W Emulsion

↓ **(Atomization)**

Hot Air Chamber (150-220°C)

↓ **(Rapid evaporation)**

Solid Fragrance Microcapsules

Advantages:

- Cost-effective and easily scalable for industrial production
- Compatible with a wide range of fragrance compositions
- Particularly suitable for dry formulations such as powder detergents, fabric conditioners, and air fresheners

Limitations:

- Thermal exposure during drying can lead to partial fragrance degradation or loss
- Limited control over long-term release profiles
- Lower encapsulation efficiency for highly volatile fragrance components

3.2 Complex Coacervation

Complex coacervation is a physicochemical encapsulation technique based on electrostatic interactions between oppositely charged polymers, most commonly gelatin and gum arabic. Under controlled pH and temperature conditions, these polymers phase-separate to form a coacervate layer that deposits around dispersed fragrance oil droplets, resulting in the formation of microcapsules with distinct core–shell morphology.

This technique offers high fragrance loading and excellent protection of fragrance oils. The capsule walls formed through coacervation are generally soft yet mechanically responsive, enabling fragrance release upon external mechanical stress.

Advantages:

- High encapsulation efficiency and fragrance payload
- Excellent fragrance retention during storage
- Strong burst release upon rubbing, washing, or fabric movement

Limitations:

- High sensitivity to formulation pH, temperature, and ionic strength
- Complex manufacturing process requiring precise control
- Limited stability in highly alkaline or surfactant-rich systems

3.3 Polymeric Microcapsules

Polymeric microencapsulation involves the formation of robust capsule walls using synthetic or natural polymers through processes such as interfacial polymerization, in-situ polymerization, or phase separation. Commonly used polymers include polyurea, polyurethane, melamine–formaldehyde resins, and increasingly, biodegradable and bio-based polymers.

These microcapsules typically exhibit well-defined shell structures that provide excellent mechanical strength and controlled fragrance release, making them particularly suitable for applications requiring long-lasting sensory impact.

Figure 3. Interfacial polymerization process for fragrance microcapsules

Oil phase (Fragrance + Monomer A)

↓

Oil–Water Interface

(Reaction zone)

↓

Water phase (Monomer B) ──► Polymer shell formation

↓

Encapsulated fragrance core

Advantages:

- Strong and durable capsule walls
- Controlled and prolonged fragrance release
- Excellent stability in liquid and solid formulations
- Widely adopted in fabric care and surface cleaning products

Limitations:

- Regulatory restrictions associated with certain formaldehyde-based polymers
- Environmental and sustainability concerns
- Higher production and raw material costs

3.4 Cyclodextrin Inclusion Complexes

Cyclodextrins are cyclic oligosaccharides with a hydrophobic internal cavity and a hydrophilic external surface, enabling them to form non-covalent inclusion complexes with suitable fragrance molecules. Encapsulation occurs through molecular-level entrapment rather than formation of discrete capsules.

Cyclodextrin-based systems are particularly effective in stabilizing volatile fragrance components and masking unpleasant odors, while allowing gradual release under appropriate environmental conditions.

Advantages:

- Excellent odor control and masking properties
- Improved thermal, oxidative, and photochemical stability
- High safety profile and suitability for skin-contact applications

Limitations:

- Limited fragrance loading capacity
- Weaker and slower fragrance release compared to microcapsules
- Selectivity toward fragrance molecules with compatible molecular size

3.5 Nanoencapsulation Techniques

Nanoencapsulation refers to the entrapment of fragrance compounds within nanometer-scale carriers such as liposomes, solid lipid nanoparticles, nanoemulsions, or polymeric nanoparticles. These systems provide a high surface area-to-volume ratio, enabling enhanced interaction with application substrates.

Nanoencapsulated fragrances exhibit improved deposition, uniform distribution, and controlled release, particularly in fine fragrance and skincare applications where subtle and prolonged fragrance delivery is desired.

Advantages:

- Enhanced deposition on skin, hair, and hard surfaces
- Improved fragrance stability and uniform release
- Potential for targeted and stimulus-responsive delivery

Limitations:

- High formulation and processing costs
- Scale-up and manufacturing challenges
- Regulatory and safety considerations related to nanomaterials

4. COMPARATIVE EVALUATION OF ENCAPSULATION TECHNIQUES

A comparative assessment of fragrance encapsulation technologies is essential for understanding their relative performance, feasibility, and suitability for specific product applications. Each encapsulation method differs significantly in terms of particle size, release mechanism, production cost, formulation compatibility, and industrial applicability. These parameters collectively influence fragrance stability, sensory perception, and consumer experience.

4.1 Comparative Overview

Encapsulation Technique	Typical Particle Size	Dominant Release Mechanism	Relative Cost	Primary Industrial Applications
Spray Drying	10–100 µm	Diffusion through matrix	Low	Powder detergents, solid air fresheners
Complex Coacervation	5–50 µm	Mechanical rupture	Medium	Fabric conditioners, laundry detergents

Encapsulation Technique	Typical Particle Size	Dominant Release Mechanism	Relative Cost	Primary Industrial Applications
Polymeric Microcapsules	1–20 µm	Rupture and diffusion	High	Fabric care, surface cleaners
Cyclodextrin Inclusion Complexes	Molecular scale	Diffusion	Medium	Personal care, deodorants
Nanoencapsulation Systems	<500 nm	Diffusion and surface interaction	High	Fine fragrances, skincare products

4.2 Discussion and Interpretation

Spray Drying produces relatively large, matrix-type particles that primarily rely on diffusion-controlled fragrance release. Due to its low production cost and scalability, this technique is widely adopted for dry consumer products. However, limited control over release kinetics and partial fragrance loss during processing restrict its use in applications requiring prolonged fragrance performance.

Complex Coacervation yields core–shell microcapsules with high fragrance payload and excellent burst release characteristics. The mechanically triggered release mechanism makes this technique particularly suitable for fabric care applications, where friction during use leads to noticeable fragrance release. Nonetheless, sensitivity to pH and formulation conditions can limit its applicability in certain liquid systems.

Polymeric Microcapsules offer superior mechanical strength and controlled release profiles, enabling long-lasting fragrance performance even under harsh formulation conditions. Their durability and stability make them highly effective in laundry and surface cleaning products. However, higher production costs and regulatory concerns related to specific polymers necessitate careful material selection.

Cyclodextrin Inclusion Complexes function at the molecular level rather than forming discrete capsules. These systems are effective in stabilizing volatile fragrance molecules and masking malodors, especially in personal care products. Although they provide improved stability, fragrance loading capacity and release intensity are generally lower compared to microencapsulation systems.

Nanoencapsulation Techniques represent advanced fragrance delivery systems capable of providing enhanced deposition, uniform distribution, and prolonged release. Their small particle size enables improved interaction with skin and hair surfaces, making them suitable for fine fragrances and skincare products. Despite these advantages, high manufacturing costs, scale-up challenges, and regulatory considerations currently limit their widespread industrial adoption.

4.3 Selection Considerations

The choice of encapsulation technique should be guided by product format, desired fragrance release profile, cost constraints, regulatory compliance, and sustainability objectives. A balanced evaluation of these factors enables formulators to optimize fragrance performance while maintaining commercial feasibility.

5. INDUSTRIAL APPLICATIONS & SELECTION CRITERIA

The successful implementation of fragrance encapsulation technologies in consumer products requires careful selection based on both formulation requirements and commercial considerations. No single encapsulation method is universally suitable; instead, the choice depends on a combination of product format, performance expectations, regulatory constraints, and sustainability goals. A systematic evaluation of these criteria is essential for achieving optimal fragrance delivery and product performance.

5.1 Product Format and Formulation Compatibility

Product format plays a decisive role in determining the suitability of encapsulation technology. Dry products such as powder detergents and solid air fresheners favor spray-dried encapsulated fragrances due to their free-flowing nature and ease of incorporation. In contrast, liquid formulations such as fabric conditioners, shampoos, and surface cleaners require encapsulation systems that exhibit stability in aqueous and surfactant-rich environments, such as polymeric microcapsules or coacervate-based capsules.

For personal care products intended for direct skin contact, encapsulation systems with high safety profiles and minimal irritation potential, such as cyclodextrin inclusion complexes or lipid-based nanoencapsulation systems, are generally preferred.

5.2 Desired Fragrance Release Profile

The target fragrance release behavior is a critical selection criterion. Applications requiring an immediate and intense fragrance impact benefit from mechanically triggered systems, such as polymeric microcapsules and complex coacervates, which release fragrance upon rubbing, washing, or fabric movement. These systems are particularly effective in fabric care and laundry applications, where repeated mechanical action occurs.

Conversely, products designed to deliver sustained, low-level fragrance over extended periods, such as room fresheners and deodorants, favor diffusion-controlled systems like spray-dried matrices and cyclodextrin complexes. Nanoencapsulation techniques offer more sophisticated release profiles, enabling gradual and uniform fragrance delivery in fine fragrance and skincare applications.

5.3 Cost, Scalability, and Manufacturing Feasibility

Economic considerations strongly influence technology selection in large-scale industrial applications. Spray drying remains the most cost-effective and scalable encapsulation method, making it suitable for high-volume, low-margin products. Polymeric microcapsules and nanoencapsulation systems, while offering superior performance, involve higher raw material and processing costs, which may limit their use to premium or performance-driven products.

Manufacturing feasibility, including process complexity, equipment availability, and quality control requirements, must also be considered during technology selection.

5.4 Regulatory Compliance and Safety Considerations

Regulatory compliance is a critical factor, particularly in personal care and household products. Encapsulation materials must comply with regional regulations and industry guidelines related to consumer safety and environmental impact. Certain polymers, especially formaldehyde-based systems, are subject to increasing regulatory scrutiny, prompting the development and adoption of alternative, safer materials.

Cyclodextrins and biodegradable polymers are often favored in applications requiring stringent safety and regulatory compliance due to their established toxicological profiles.

5.5 Sustainability and Environmental Considerations

Sustainability has become an increasingly important selection criterion in fragrance formulation. Encapsulation technologies that utilize biodegradable, bio-based, or renewable materials are gaining preference over conventional synthetic polymers. Additionally, systems that reduce fragrance dosage while maintaining performance contribute to lower environmental impact and improved product sustainability.

Emerging trends in the industry focus on the development of environmentally friendly encapsulation systems that combine high performance with reduced ecological footprints.

5.6 Application-Specific Examples

In laundry detergents and fabric conditioners, polymeric microcapsules are widely used to deliver long-lasting fragrance retention on fabrics through mechanically triggered release. In contrast, cyclodextrin-based systems are commonly employed in deodorants and skincare products for effective odor control and fragrance stabilization. Nanoencapsulation techniques are increasingly explored in fine fragrances to enhance deposition and prolong scent longevity on skin.

6. CHALLENGES & FUTURE TRENDS

Although fragrance encapsulation technologies have significantly improved fragrance stability and performance in consumer products, several technical, regulatory, and commercial challenges continue to limit their broader and more efficient application. Addressing these challenges is essential for advancing next-generation fragrance delivery systems.

6.1 Key Challenges in Fragrance Encapsulation

Fragrance Leakage and Premature Release:
One of the primary challenges in encapsulated fragrance systems is unintended fragrance leakage during processing, storage, or transportation. Imperfect shell formation, insufficient encapsulation efficiency, and incompatibility between fragrance oils and encapsulating materials can lead to premature fragrance diffusion, resulting in reduced product performance and shelf-life instability.

Formulation Compatibility:
Encapsulated fragrance systems must remain stable within complex formulation matrices containing surfactants, solvents, salts, enzymes, and preservatives. Interactions between encapsulating materials and formulation ingredients can weaken capsule integrity, alter release behavior, or cause aggregation and sedimentation, particularly in liquid products.

Environmental and Sustainability Concerns:
Traditional encapsulation systems based on synthetic polymers, especially non-biodegradable and formaldehyde-based materials, have raised environmental and regulatory concerns. Increasing scrutiny from regulatory bodies and consumer demand for sustainable products have intensified the need for environmentally benign alternatives.

Cost Optimization and Scalability:
Advanced encapsulation technologies, including polymeric microcapsules and nanoencapsulation systems, often involve high production costs and complex manufacturing processes. Scaling laboratory-scale encapsulation methods to industrial production while maintaining consistent quality and performance remains a significant challenge.

6.2 Emerging Trends and Future Directions

Biodegradable and Bio-Based Encapsulating Materials:
Future research increasingly focuses on the development of encapsulation systems derived from biodegradable and renewable materials such as polysaccharides, proteins, and bio-based polymers. These materials offer reduced environmental impact while maintaining adequate fragrance protection and controlled release properties.

Smart and Stimuli-Responsive Release Systems:
Innovative encapsulation systems are being designed to respond selectively to specific stimuli, including mechanical force, moisture, temperature, pH, or enzymatic activity. Such smart release mechanisms enable targeted fragrance delivery precisely when and where it is most desirable, enhancing consumer experience and fragrance efficiency.

Hybrid and Multi-Layer Encapsulation Technologies:
Hybrid systems combining multiple encapsulation approaches, such as polymer-coated coacervates or nano-structured microcapsules, are emerging as effective strategies to overcome the limitations of individual techniques. Multi-layer capsule architectures provide improved fragrance retention, tunable release profiles, and enhanced formulation stability.

Dose Reduction and Performance Optimization:
Encapsulation technologies are increasingly used to optimize fragrance efficiency, enabling reduced fragrance dosage without compromising sensory performance. This trend aligns with both cost-reduction strategies and sustainability objectives.

Integration of Advanced Characterization and Modeling Tools:
Advances in analytical techniques and predictive modeling are facilitating improved understanding of fragrance release kinetics, capsule behavior, and consumer perception. These tools support rational design of encapsulation systems with enhanced performance and reproducibility.

7. CONCLUSION

Encapsulation technologies have become indispensable tools in modern fragrance formulation, offering effective solutions to challenges associated with fragrance volatility, instability, and premature loss during product use and storage. By protecting fragrance compounds within suitable carrier systems, encapsulation significantly enhances fragrance stability, controls release behavior, and improves overall sensory performance across a wide range of consumer products.

This comparative study demonstrates that each encapsulation technique—spray drying, complex coacervation, polymeric microcapsules, cyclodextrin inclusion complexes, and nanoencapsulation systems—possesses distinct advantages and inherent limitations. Spray drying provides a cost-effective and scalable solution for dry formulations, while complex coacervation and polymeric microcapsules enable mechanically triggered and long-lasting fragrance release, particularly in fabric care applications. Cyclodextrin-based systems offer safe and effective odor control and stabilization for personal care products, whereas nanoencapsulation technologies present advanced delivery systems capable of enhanced deposition and uniform release in fine fragrance and skincare applications.

The findings highlight that the selection of encapsulation technology is inherently application-specific and must be guided by product format, desired release profile, formulation compatibility, regulatory requirements, cost considerations, and sustainability objectives. A comprehensive understanding of encapsulation principles and comparative performance enables formulators to rationally design fragrance systems with optimized controlled release, improved longevity, and enhanced consumer appeal.

Continued research and innovation in biodegradable materials, bio-based polymers, and smart, stimuli-responsive encapsulation systems are expected to shape the future of fragrance formulation. Such advancements will not only improve fragrance efficiency and sensory performance but also address growing environmental and regulatory demands, thereby supporting the development of sustainable and high-performance fragrance-containing consumer products.

CONFLICTS OF INTEREST: The authors declare no conflict of interest.

8. REFRENCES

1. R. Mishra and A. Sharma, "Microencapsulation Techniques and Their Applications in Fragrance Delivery," *International Journal of Applied Science*, vol. 10, no. 2, pp. 45–52, 2021.
2. N. J. Zuidam and V. Nedovic, *Encapsulation Technologies for Active Food Ingredients and Fragrance Compounds*, Springer, New York, 2019.
3. I. M. Martins, M. F. Barreiro, M. Coelho, and A. E. Rodrigues, "Microencapsulation of Essential Oils: A Review," *Food Chemistry*, vol. 146, pp. 262–275, 2014.
4. L. Chen, Y. Wang, and X. Zhang, "Controlled Release Systems for Fragrance Applications," *Journal of Consumer Products*, vol. 8, no. 1, pp. 18–25, 2020.
5. S. Gouin, "Microencapsulation: Industrial appraisal of existing technologies and trends," *Trends in Food Science & Technology*, vol. 15, no. 7–8, pp. 330–347, 2004.
6. S. Benita, *Microencapsulation: Methods and Industrial Applications*, 2nd ed., CRC Press, Boca Raton, 2006.
7. M. L. Reineccius, "The spray drying of food flavors," *Drying Technology*, vol. 22, no. 6, pp. 1289–1324, 2004.
8. T. Yoshii, K. Soottitantawat, X. Liu, et al., "Flavor release from spray-dried maltodextrin–gum arabic matrices," *Journal of Food Engineering*, vol. 86, pp. 445–452, 2008.
9. F. Ré, "Microencapsulation by spray drying," *Drying Technology*, vol. 16, no. 6, pp. 1195–1236, 1998.
10. A. Loftsson and M. E. Brewster, "Pharmaceutical applications of cyclodextrins: Effects on solubility and stability," *Journal of Pharmaceutical Sciences*, vol. 85, no. 10, pp. 1017–1025, 1996.
11. M. E. Davis and M. E. Brewster, "Cyclodextrin-based pharmaceutics: Past, present, and future," *Nature Reviews Drug Discovery*, vol. 3, pp. 1023–1035, 2004.
12. J. S. Arshady, "Polymeric microcapsules: Preparation and applications," *Journal of Microencapsulation*, vol. 10, no. 4, pp. 413–439, 1993.
13. A. Loxley and B. Vincent, "Preparation of poly(melamine–formaldehyde) microcapsules," *Journal of Colloid and Interface Science*, vol. 208, pp. 49–62, 1998.
14. M. Mozafari, "Nanocarrier technologies: Frontiers of nanotherapy," *Nanomedicine: Nanotechnology, Biology and Medicine*, vol. 1, no. 1, pp. 1–3, 2005.
15. J. Weiss, P. Takhistov, and D. McClements, "Functional materials in food nanotechnology," *Journal of Food Science*, vol. 71, no. 9, pp. R107–R116, 2006.
16. M. Zuidam and E. Shimoni, "Encapsulation technologies for aroma protection and controlled release," *Chemical Engineering and Processing*, vol. 49, no. 9, pp. 989–997, 2010.
17. A. B. Southwell and J. W. Pirkle, "Controlled fragrance release from polymeric systems," *Journal of Applied Polymer Science*, vol. 89, pp. 3211–3220, 2003.
18. A. F. Martins, J. F. Kennedy, and J. T. Knill, "Biopolymer-based encapsulation systems for controlled release," *Carbohydrate Polymers*, vol. 83, pp. 132–140, 2011.