

Hydrogenated Castor Oil Micro particles: Synthesis, Characterization, and Application in Oleo-Chemical Industry

Vaibhav M. Gawande¹, Vijay Y. Karadbhajne¹, Ruta D. Khonde², Lipigya A. Taklikar¹

1. Department of Oil Technology, Laxminarayan Innovation Technological University, Nagpur, IND

2. Department of Chemical Engineering, Priyadarshini College of Engineering, Nagpur, IND

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Abstract

The present study investigates the synthesis and characterization of hydrogenated castor oil (HCO) solid lipid microparticles as a sustainable, eco-friendly alternative to commercial synthetic chemical carriers to enhance chemical and physical stability of solid lipid microparticles that function as solvents, stabilizer, and capping agent. With hot homogenization technique followed by high-energy ultrasonication, HCO was processed with a 1% polyvinyl alcohol surfactant to develop a stable oil-in-water microemulsion. Physicochemical characterization confirmed the micro-scale morphology of the particles, yielding a Z-average particle size of 733.6 nm and a mean diameter of 439.2 nm. Thermal stability and phase transition behaviors were analyzed using differential scanning calorimetry, while the surface charge was recorded at a zeta potential of 0.9 mV. Furthermore, Fourier transform infrared spectroscopy verified the structural integrity of the lipid matrix by identifying key functional groups, including C=O, C-H, C-O-C, and O-H. The results demonstrate that synthesized microparticles possess a robust physical profile and a high surface-to-volume ratio, making them highly versatile for advanced applications as stabilizers, solvents, and capping agents within the oleo-chemical and pharmaceutical sectors.

Categories: Advanced Materials, Chemical Process Optimization, Sustainable Technologies

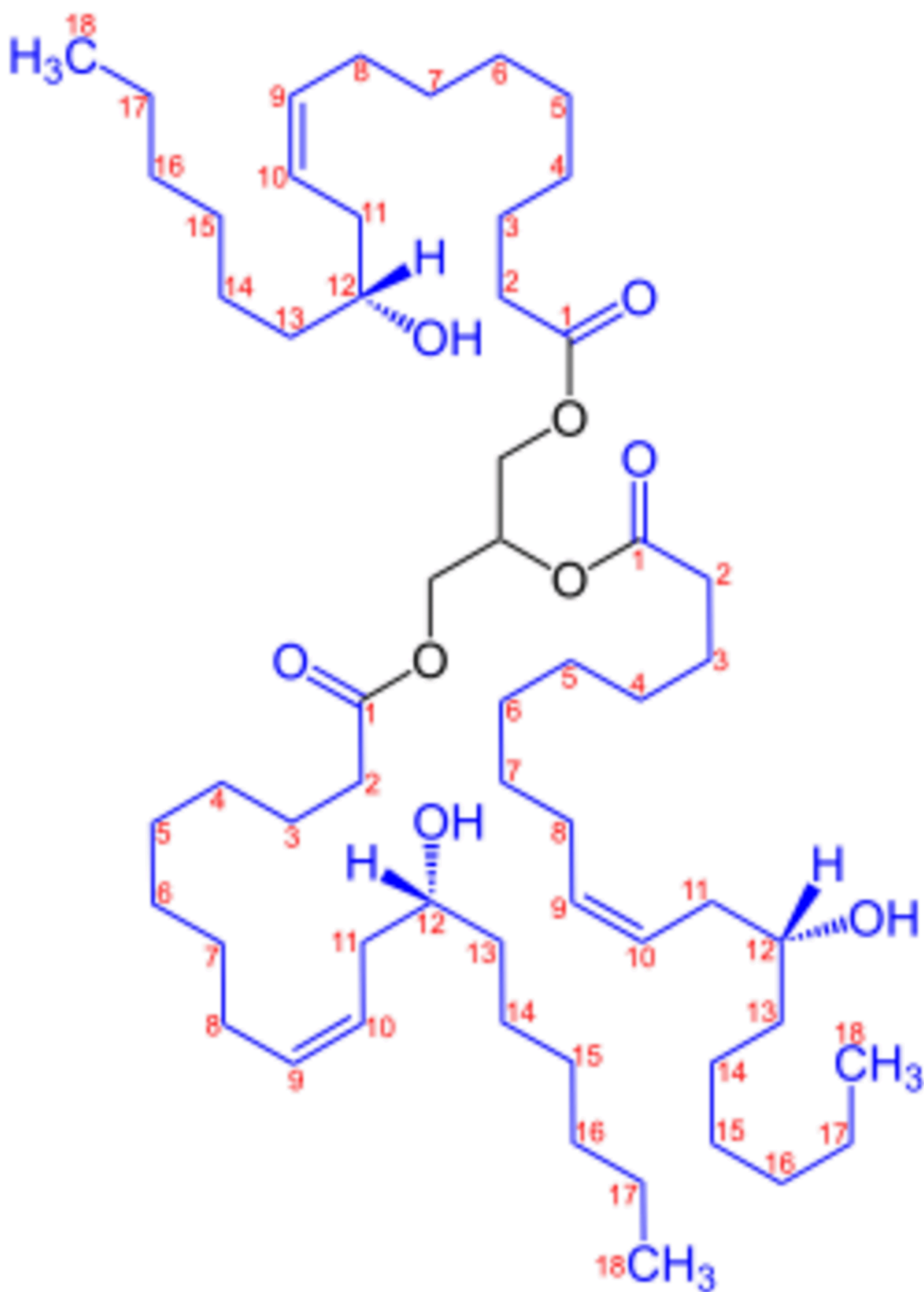
Keywords: hydrogenated castor oil, micro-emulsion, emulsifier, stabilizer, oleochemical, rheology modifiers, solid lipid microparticles, ricinoleic acid, nickel catalyst, hydrogenation

Introduction

Castor oil has long served as a vital, highly renewable feedstock for the global chemical industry. Extracted by pressing the seeds of the castor plant (*Ricinus communis* L.), which is primarily cultivated in the tropical and subtropical regions of Africa, South America, and Asia [1]. Historically, the plant is believed to have been domesticated in Eastern Africa before being introduced to China via India approximately 1,400 years ago. Today, the global market is dominated by India, which serves as a net exporter accounting for over 90% of global castor oil exports [2]. Conversely, the United States, the European Union, and China constitute the primary importers, representing 84% of the world's total import volume.

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FIGURE 1: Structure of castor oil showing major components such as tri-ester of glycerol and ricinoleic acid

Physically, castor oil is a viscous, pale-yellow to colorless liquid with a distinct odor, an exceptionally high boiling point of approximately 313°C, and excellent thermal stability. It serves as a valuable industrial resource due to its low cost, biodegradability, non-toxicity, and abundant availability as a non-food crop [2]. In industrial chemistry, its unique utility stems from being a rich natural source of hydroxylated fatty acids, which offer a versatile platform for chemical synthesis and specialized derivatives [1]. This specific hydroxylated structure also allows the oil to function effectively as a green capping agent and stabilizer during nanomaterial synthesis. Naturally, the oil's fatty acid profile is dominated by ricinoleic acid - a monounsaturated, 18-carbon hydroxylated fatty acid comprising roughly 90% of its total composition, with minor amounts of linoleic, oleic, stearic, palmitic, erucic, and eicosadienoic acids. Figure 1 shows structural components of castor oil. The complete percentage profiles for these components, as well as the specialized derivatives resulting from the hydrogenation of castor oil, are summarized in Table 1 [3,4].

Fatty acids	Composition (%)
Palmitic acid (C16:0)	2.59
Linoleic acid (C18:2)	10.35
Oleic acid (C18:1)	7.55
Stearic acid (C18:0)	2.81
Ricinoleic acid (C18:1)	74.10
Eicosadienoic acid (C20:2)	0.93
Erucic acid (C22:1)	1.70

TABLE 1: Average composition of hydrolyzed castor oil fatty acid

Conventionally, hydrogenated castor oil is produced by the reduction of castor oil by the addition of hydrogen gas in the presence of a nickel catalyst. These are characterized by a melting point of 86°C. Hydrogenation improves the chemical and physical stability of oil/fat. Due to this, it is used in various cosmetics and medicinal formulations. The synthesis of HCO involves a controlled catalytic hydrogenation reaction. In this process, pure hydrogen gas is introduced to the liquid castor oil under high pressure and temperature. A nickel catalyst is typically employed to facilitate the reduction of the carbon-carbon double bonds (C=C) present in the ricinoleic acid chains. This chemical reduction transforms the unsaturated fatty acids into saturated ones, effectively turning a liquid triglyceride into a solid lipid.

The advantages of HCO-SLNs can be summarized as follows:

- Useful for transforming a waxy, bulk substance into a controlled, high-surface-area colloidal carrier system. While raw HCO is limited to acting as a basic thickener or wax in formulations, SLMs allow for targeted, sustained release and enhanced stability of active pharmaceutical ingredients.

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- Can modulate the release of encapsulated drugs over an extended period.
- Enhances the solubility and consequently, the oral bioavailability of poorly water-soluble (Class II and IV) drugs.
- Protects sensitive or chemically unstable ingredients from degradation caused by light, moisture, or oxidation.
- Can carry high payloads of lipophilic drugs.
- Active ingredients can be incorporated into the lipid system without needing complex chemical modification, ensuring the stability of the compound.

Several applications of HCO-SLNs in oleo-chemical industries are as follows:

1. As a rheological agent and thixotrope (like paints/inks): Micronized HCO is used as a thickening agent, providing thixotropy (shear-thinning) to paints, industrial coatings, inks, and sealants, improving their viscosity and application properties.
2. For lubricant and grease manufacturing: HCO is crucial in producing high-performance Lithium and Calcium complex greases, providing high-temperature, water, and oil resistance. It is also used as a metal-drawing lubricant.
3. In plastic and rubber processing: Acts as an internal lubricant and anti-tack/slip additive in plastic manufacturing such as PVC, PE, PS, and rubber molding, improving mold release and reducing surface friction.
4. As an agent in hot-melt adhesives and coatings: Used as a modifying agent in hot-melt adhesives for packaging, bookbinding, and as a coating agent for paper and textiles to provide water resistance.
5. In cosmetic and personal care formulations: Due to its excellent emollient properties, it is used as a thickener and stabilizer in lipsticks, lotions, creams, and deodorant sticks.
6. In pharmaceutical excipients: Functions as a binder and lubricant in tablet and capsule production, and as a component in controlled-release coatings.
7. As a specialty chemical derivative: Serves as a raw material for creating derivatives such as ethoxylated hydrogenated castor oil, which acts as a non-ionic surfactant/emulsifier in agrochemicals and cleaning products.

Literature

Early research focused heavily on poly(lactic-co-glycolic acid) (PLGA) and its interaction with emulsifiers like polyvinyl alcohol (PVA). Researchers discovered that PVA was irreversibly adsorbed to the nanoparticle surface during synthesis, with this residual layer acting as a hydrophilic barrier dictating how particles interact with cells [5]. Another study revealed that excessive residual PVA hindered cellular uptake, highlighting a critical trade-off in formulation design [6].

As research progressed, a hybrid approach emerged that combined the stability of polymers with the biocompatibility of lipids. Using PLGA as a polymeric emulsifier rather than a base material, researchers solved the long-standing problem of loading water-soluble proteins into solid lipid nanoparticles [7]. This hybrid strategy proved highly effective for the oral delivery of insulin and interferon, protecting these sensitive molecules from the harsh environment of the stomach and allowing for a controlled, long-term release [8,9]. The chemical composition of the polymer, specifically the ratio of lactic to glycolic acid, was found to be a primary factor in controlling these emulsifying properties [10].

A major breakthrough for poorly soluble drugs was the discovery that lipid nanoparticles could bypass "first-pass metabolism" in the liver. By engineering particles that are absorbed through the lymphatic system, researchers were able to increase the bioavailability of memory-enhancing drugs like vinpocetine by over 300% [11]. This shifted the focus toward creating highly specialized lipid matrices that could carry a variety of drug types while ensuring maximum absorption and minimal systemic toxicity.

Some studies emphasized the transition toward green nanotechnology, specifically utilizing castor oil and its derivative, ricinoleic acid. Hydrogenated castor oil (HCO) has proven to be a superior matrix for anti-parasitic and antibiotic drugs, offering a depot effect that extends the residence time of drugs in the bloodstream [12,13]. Beyond medicine, the unique

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chemical structure of castor oil allows it to act as a "capping agent" that stabilizes silver and semiconductor (CdS) nanoparticles without the need for toxic lab chemicals [1,4]. This green synthesis method is not only safer but also allows for fine-tuning the electronic and optical properties of the materials [3].

Thus, the versatility of castor oil extends into advanced materials science and industrial engineering. Because it is rich in heavy hydrocarbons, it has been successfully used as a botanical precursor for growing carbon nanotubes and nanofibers without expensive catalysts [14]. Simultaneously, its high dielectric strength has led to the development of vegetable oil-based nanofluids for high-voltage electrical insulation [2]. These fluids dissipate heat more efficiently than traditional mineral oils, representing a significant step toward making heavy industrial components more sustainable and efficient.

While some recent studies focus broadly on castor oil processing and extraction of ricinoleic acid rather than exclusively on hydrogenated castor oil microparticles, they have also established the fundamental chemical, biocatalytic, and thermal principles required for the synthesis of castor oil derivatives in the oleo-chemical industry. A chemical baseline was provided for generating the high-purity ricinoleic acid precursor required before hydrogenation or microparticle encapsulation in green oleo-chemical processing [15]. Another study evaluated thermal cracking, pyrolysis, and dehydration behaviors of castor oil and provided critical characterization data on thermal treatments that alter double bonds and hydroxyl groups, dictating thermal resistance, melting point, and stability of solid wax microparticles, like HCO, in industrial lubricants and coatings [16]. The use of ionic liquids has been demonstrated to overcome high viscosity and mass-transfer barriers during biocatalysis. This technique is directly relevant to optimizing reaction media for uniform microparticle synthesis and controlled lipid extraction [17]. Recent research explored surfactant-assisted, immobilized lipase reactions such as cross-linking and entrapment to lower the interfacial tension. Authors reported an emulsion and dispersion framework that is necessary to form stable, uniform micro- and nano-droplets during solid lipid microparticle fabrication [18].

Although hydrogenated castor oil has been widely researched as a lipid matrix for solid lipid nanoparticles in drug delivery systems, there is a significant lack of investigation on the synthesis, optimization, and comprehensive characterization of hydrogenated castor oil microparticles for industrial applications. Existing studies primarily emphasize biomedical uses, while the potential of HCO microparticles as sustainable bio-based materials for the oleochemical industry, such as lubricants, coatings, waxes, specialty additives, and controlled-release formulations, remains largely unexplored. Addressing these gaps, this investigation facilitates the development of renewable, high-performance oleochemical materials that reduce dependence on petroleum-derived products. Table 2 reveals that most of the research focused on drug delivery systems, however this research is focusing on its potential applications in oleo-chemical industries.

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Researches focused on drug delivery systems	This research focusing oleo-chemical industrial applications
Main objective is controlled delivery of drugs and improved bioavailability.	Main objective is development of sustainable bio-based microparticles for industrial oleochemical products.
Mainly consists of solid lipid nanoparticles and nanostructured lipid carriers.	Mainly consists of Hydrogenated castor oil solid lipid microparticles.
Size typically ranges between 50 and 500 nm.	Size typically ranges between 1 and 500 μm .
Core material is hydrogenated castor oil with pharmaceutical excipients.	Core material is hydrogenated castor oil with industrial additives.
Encapsulated materials are drugs, peptides, proteins, vaccines.	These contain lubricant additives, antioxidants, fragrances, corrosion inhibitors, catalysts, agrochemicals.
Principles of synthesis are high-pressure homogenization, hot homogenization, and microemulsion.	Preparation methods include spray chilling, spray congealing, melt dispersion, and fluidized-bed coating.
Characterization techniques used are particle size, zeta potential, encapsulation efficiency, drug release, cytotoxicity.	FTIR, DSC, TGA, XRD, SEM, particle size, rheology, flowability, thermal stability, storage stability are used to characterize.
Performance evaluation depends on drug release kinetics, bioavailability, and therapeutic efficacy.	Performance evaluated based on mechanical stability, oxidation resistance, controlled industrial release, and processability.
Typical applications include oral, topical, ocular, pulmonary, injectable drug delivery	Typically used in lubricants, coatings, waxes, cosmetics, agrochemicals, specialty chemicals

TABLE 2: Comparison of drug delivery systems with oleo-chemical industrial applications of HCO microparticles

FTIR, Fourier Transform Infrared Spectroscopy; DSC, Differential Scanning Calorimetry; TGA, Thermogravimetric Analysis; XRD, X-Ray Diffraction; SEM, Scanning Electron Microscopy; HCO, Hydrogenated Castor Oil

Materials And Methods

Preparation of HCO microparticles

Solid lipid microparticles were prepared by the hot homogenization and ultrasonication method. HCO (1.6 g) was poured into a 50 mL tube and put in a boiling water bath. After the lipid was melted, 40 mL of 1% PVA solution preheated in a boiling water bath was poured into the lipid phase under magnetic stirring to form an oil-water emulsion, and then sonicated for 5 min (make: Vibra-Cell, model: VCX750, Sonics and Materials, Inc., Newtown, CT, USA, with a 13 mm microprobe and an amplitude of 35%) to form a micro-emulsion. The hot micro-emulsion was quickly poured into 200 mL of cold water to obtain a suspension of microparticles. The microparticles were collected by centrifugation at 12,000 rpm (make: Centrifuge C-24, REMI India) for 90 min at 4°C and washed three times with distilled water. The SLMs were suspended in 30 mL of distilled water and lyophilized for 48 h (make: LGJ-12 Freeze Dryer; Beijing Songyuanhuaxing Science Technology Development Co., Ltd, China). The same process was used for another composition.

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Characterization

Though the process for nanoparticle formation was utilized, we obtained microparticles of HCO in the laboratory experiments. The synthesized microparticles were characterized for particle size using a Particle Size Analyzer (PSA), functional group content using Fourier Transform Infra-Red Spectroscopy (FTIR), and thermal behavior at variable temperatures using Differential Scanning Calorimeter (DSC). These analyses were performed in the Department of Pharmaceutical Sciences, R T M Nagpur University, Nagpur.

Method of Particle Size Analysis

The systematic method of PSA (make: HORIBA, model: SZ-100) as shown in Figure 2, involves connecting the analyzer and computer system, selecting the appropriate cell type, preparing and loading the sample, and configuring measurement parameters through the software. Sample-specific information such as refractive index, viscosity, temperature, and measurement conditions were chosen before initiating analysis. The instrument enables particle size mode, and a spectrum of particle size distribution is recorded by the instrument. Key precautions include ensuring that clean and contaminant-free cuvettes are used for loading the sample to ensure accurate and reliable measurements.

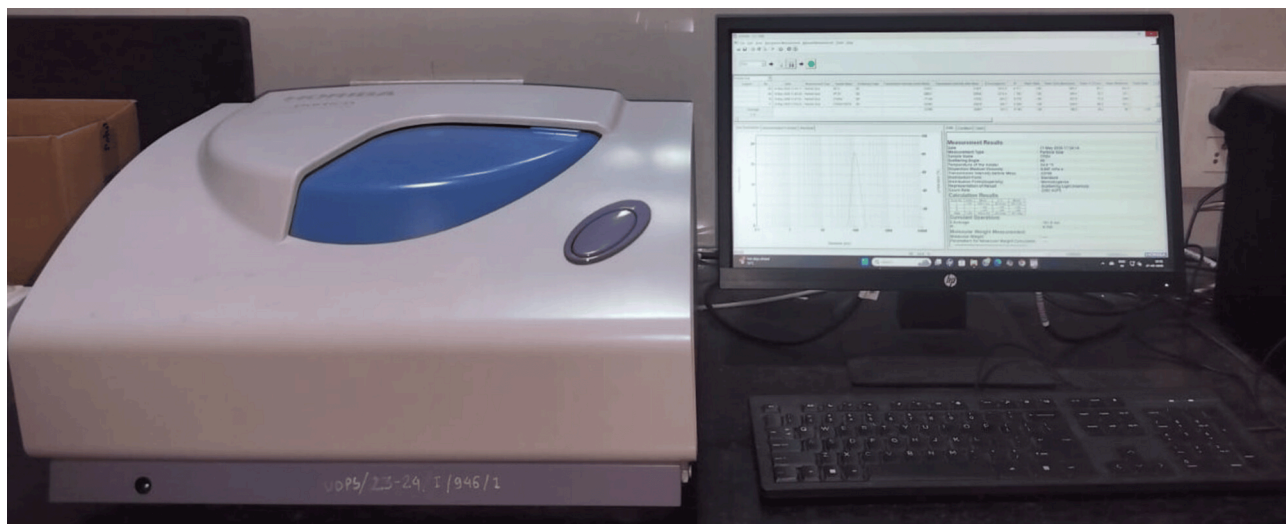


FIGURE 2: Particle size analyzer

Method of Fourier Transform Infrared Analysis

FTIR coupled with Attenuated Total Reflectance (ATR, make: Shimadzu, model: IRSpirit) as shown in Figure 3, was used to identify functional groups and characterize the chemical composition of materials using a non-destructive analytical technique. The general methodology of operation is based on the absorption of infrared radiation by molecular bonds at specific frequencies corresponding to their vibrational modes. During operation, the infrared beam is directed through an optically dense crystal with a high refractive index, where it undergoes total internal reflection. This generates an evanescent wave that penetrates a few micrometers into the sample placed in direct contact with the crystal surface. The absorbed infrared energy produces a characteristic spectrum that serves as a molecular fingerprint of the sample, enabling qualitative and quantitative analysis of its chemical structure and composition.

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FIGURE 3: Fourier transform infrared analyzer

Method of Differential Scanning Calorimetry Analysis

The methodology of DSC as shown in Figure 4, is used for thermal analysis to describe the melting point, glass transition temperature, crystallinity, and thermal stability of the sample. A precisely weighed sample (typically 2 to 10 mg) is sealed in an aluminum DSC pan, while another empty sealed pan is used as a reference. Both pans are placed in the DSC cell, and experimental conditions such as temperature range, heating rate, and purge gas flow are set before initiating the analysis. During operation, the thermal behavior of the sample is monitored and recorded as thermograms. After completion, the system is allowed to cool, the pans are removed, and the data in the form of a thermogram and table are saved for analysis. To ensure accurate and safe operation, precautions such as proper pan sealing, continuous purge gas supply, and regular instrument calibration are important.

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FIGURE 4: Differential scanning calorimetry analyzer

Results And Discussion

Based on characterization, Silverstein et al. [19] established the core principles of spectroscopic identification, which Gupta and Sharma [20] apply practically by using FTIR spectroscopy to map the functional groups and chemical modifications of castor oil. Complementing this molecular analysis, Shaw [21] delivered the foundational physical chemistry rules governing interfaces, emulsions, and colloidal stability, while Naito et al. [22] translate these concepts into practical engineering guidelines for processing and characterizing nanoparticles.

Particle size analysis

The particle size analysis of hydrogenated castor oil was carried out using a PSA (make: HORIBA, model: SZ-100) at a 90° scattering angle and a temperature at 25°C. This result represents the scattering light intensity and a count rate of 65 KCPS with standard distribution form. Figure 5 reveals mono-disperse behavior of HCO microparticles with a Z-average of 733.6 nm. The results show the mono-disperse behavior with a Z-average of 733.6 nm. This indicates that the particle is uniform in size and represents the polydispersity index, which was found to be 0.839, indicating a broad size distribution of particles.

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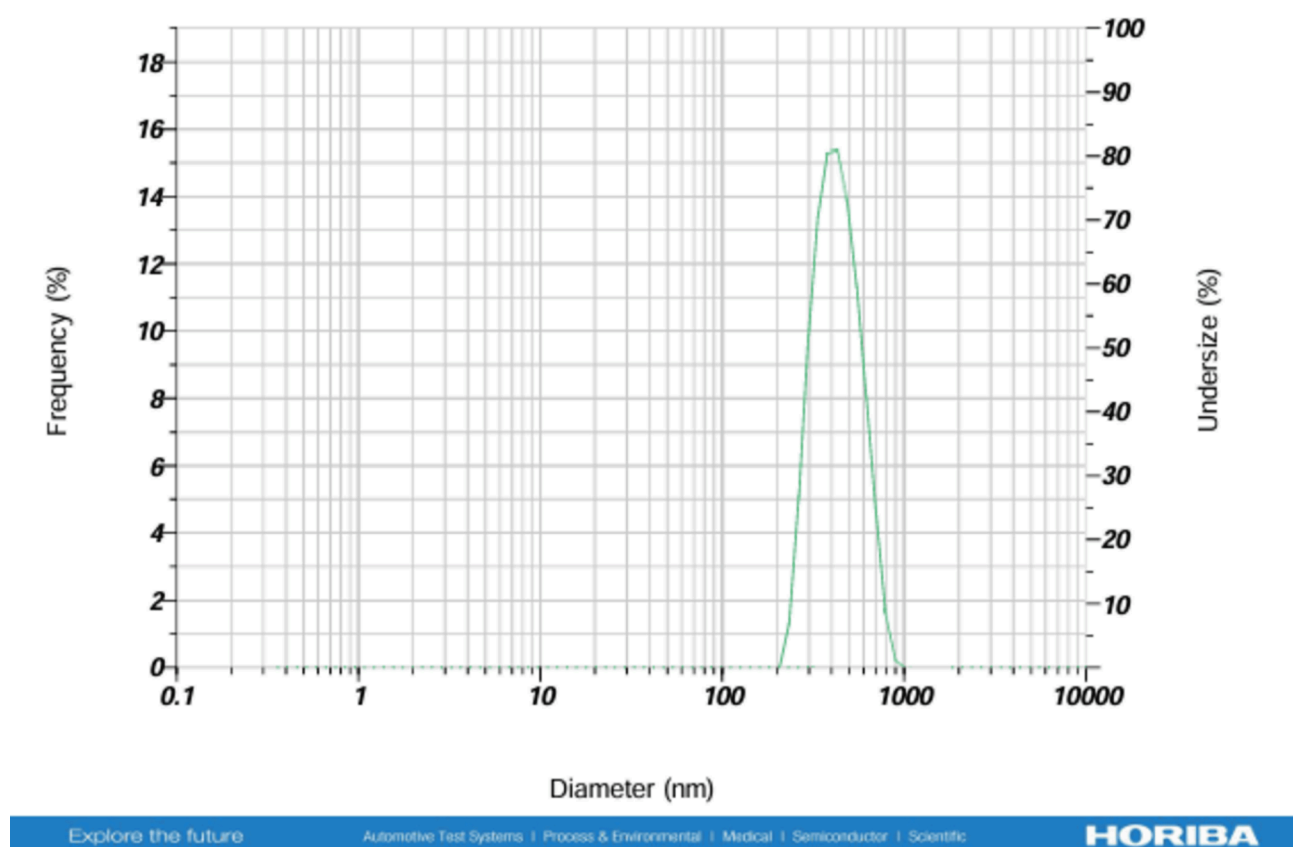


FIGURE 5: Particle size analysis of HCO

HCO, hydrogenated castor oil

The graph represents the particle size analysis of hydrogenated castor oil, where the x-axis indicates particle diameter in nm and the y-axis indicates the percentage frequency of particles within a particular size range. The graph shows the relationship between particle size and the frequency of particles. This result indicates the successful synthesis of hydrogenated castor oil having various applications in industrial and pharmaceutical formulations.

Fourier Transform Infra-Red Spectroscopy

FTIR spectroscopic analysis was performed to identify the functional groups present in hydrogenated castor oil microparticles and to confirm the chemical structure of the synthesized material. Figure 6 shows FTIR spectrum of HCO SLM recorded in the range of 4000-500 cm^{-1} . The FTIR spectrum was recorded in the range of 4000-500 cm^{-1} . The FTIR spectrum revealed several characteristic absorption peaks corresponding to functional groups present in hydrogenated castor oil. A broad absorption band observed at 3370 cm^{-1} corresponds to O-H stretching vibrations, indicating the presence of hydroxyl groups. The peak around 1464 cm^{-1} corresponds to CH_2 bending vibrations, further supporting the presence of long hydrocarbon chains. Peaks observed at 1242 cm^{-1} and 1026-1102 cm^{-1} are assigned to C-O stretching vibrations of ester and alcohol groups, confirming the ester linkage in the hydrogenated castor oil structure. The FTIR spectra determined the peak at 1740 cm^{-1} indicates C=O, peak at 2851 cm^{-1} indicates C-H stretching, peak at 1102.81 cm^{-1} indicates C-O-C, peak at 3370 cm^{-1} indicates O-H group. Thus, the FTIR spectrum confirms the presence of hydroxyl, ester, and long aliphatic hydrocarbon groups, indicating the successful synthesis of hydrogenated castor oil microparticles without significant structural modification of the parent compound.

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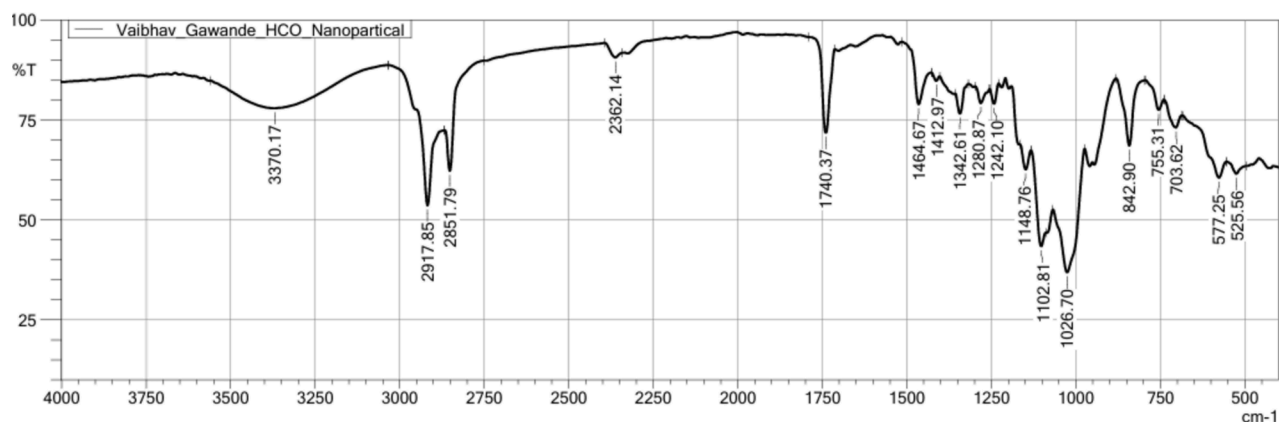


FIGURE 6: FTIR of HCO SLM

HCO SLM, Hydrogenated Castor Oil Solid Lipid Microparticles; FTIR, Fourier Transform Infrared Spectroscopy

Differential scanning calorimetry

The thermal behavior of HCO microparticles was analyzed using DSC to determine their thermal stability and phase transition characteristics. The DSC thermogram was recorded over a temperature range of 30 to 220°C with a heating rate of 10°C/min under a nitrogen atmosphere. The DSC spectra as available in Figure 7 revealed a distinct endothermic peak between 44 and 47°C, indicating the melting transition of hydrogenated castor oil. The DSC spectra revealed a distinct endothermic peak between 44 and 47°C, indicating the melting transition of hydrogenated castor oil. The onset of the thermal event occurs around 44.6°C, where the heat flow decreases to −4.488 mW, followed by a peak minimum at approximately 46.9°C with a heat flow of −5.458 mW. After the melting event, the thermogram gradually stabilizes and shows a relatively flat heat flow profile from 50 to 200°C, suggesting that the material remains thermally stable within this temperature range. No additional major thermal transitions or decomposition peaks were observed, indicating good thermal stability of the synthesized microparticles. Therefore, the DSC analysis demonstrates that the synthesized hydrogenated castor oil microparticles exhibit a well-defined melting transition and good thermal stability, making them suitable for potential applications in the oleochemical industry.

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Module: DSC
 Data Name: HCO-NVAIBHAV
 Measurement Date: 02-04-2025
 Sample Name: HCO-NVAIBHAV
 Sample Weight: 2.900 mg
 Reference Name: empty
 Reference Weight: 0.000 mg

Temperature Program:
 Cel Cel Cel/min min s
 1* 30 220 10 5 0.5

Comment:
 Operator: Wadetwar/PC/Dept. of pceutical
 Gas1: N2
 Pan: Al

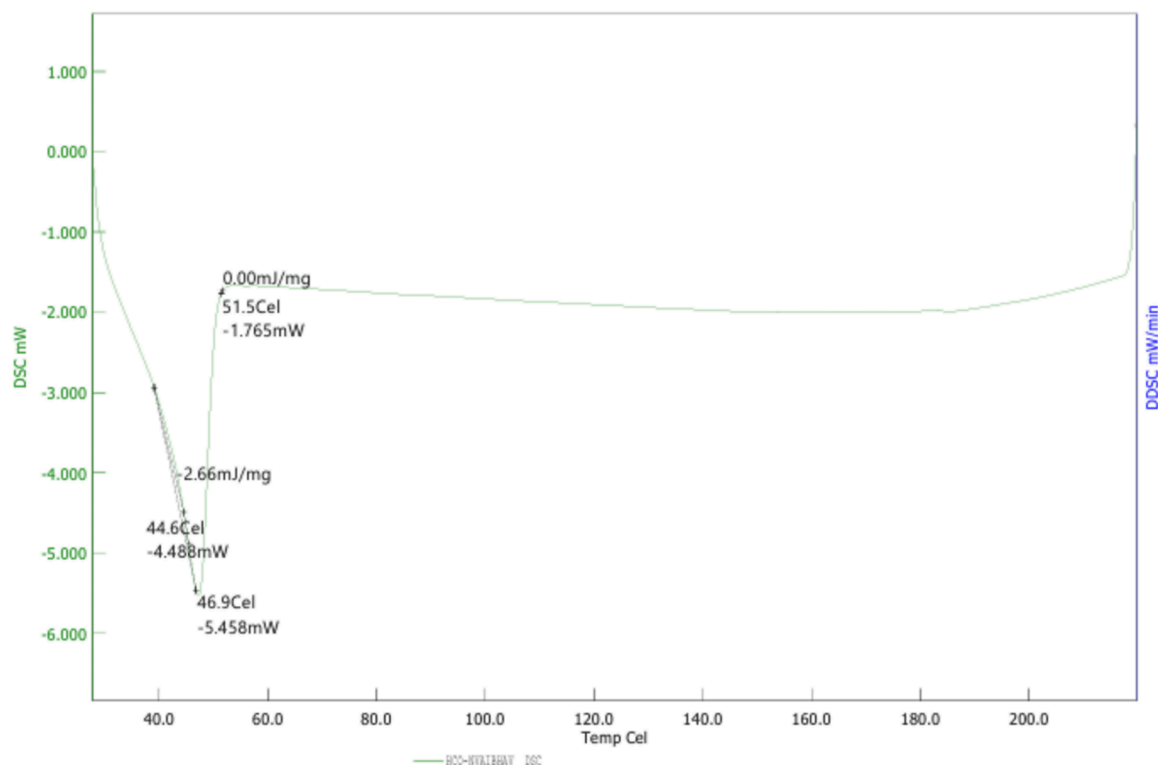


FIGURE 7: Differential scanning calorimetry of HCO SLM

HCO SLM, Hydrogenated Castor Oil Solid Lipid Microparticles

Conclusions

HCO microparticles were synthesized in this investigation, resulting in a stable lipid-based delivery system with a Z-average value of 733.6 nm and a mean diameter of 439.2 nm. This confirms that the chosen fabrication method is effective for producing sub-micron particles with consistent dimensional properties. The structural and thermal integrity of these HCO microparticles was rigorously validated through a comprehensive suite of characterization techniques, including PSA, FTIR, and DSC studies. These analyses collectively confirmed the chemical stability and phase behavior of the lipid matrix. The characterization performed for these microparticles establishes a robust foundation for their utilization as sustainable, bio-derived carriers in advanced materials science. By confirming the precise physical and chemical markers of the HCO particles, this research bridges the gap between raw oleo-chemical processing and high-value functional applications, proving that hydrogenated castor oil is a viable and versatile candidate for solid lipid-based encapsulation technologies.

Future research may prioritize transitioning to the nanoscale by optimizing surfactant ratios and ultrasonication to produce SLNs below 200 nm. This reduction in size will significantly enhance the surface area-to-volume ratio, improving the performance of the lipid matrix in specialized delivery and coating applications. Also, utilizing alternative fabrication

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methods like high-pressure homogenization and advanced imaging will help evaluate particle morphology and long-term stability. Thus, investigating the loading efficiency of bioactive compounds will reveal new, sustainable pathways for HCO-based particles within the oleo-chemical and biomedical sectors.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Vaibhav M. Gawande, Vijay Y. Karadbhaje, Ruta D. Khonde, Lipigya A. Taklikar

Acquisition, analysis, or interpretation of data: Vaibhav M. Gawande, Vijay Y. Karadbhaje, Ruta D. Khonde

Drafting of the manuscript: Vaibhav M. Gawande, Vijay Y. Karadbhaje, Ruta D. Khonde, Lipigya A. Taklikar

Critical review of the manuscript for important intellectual content: Vaibhav M. Gawande, Vijay Y. Karadbhaje, Ruta D. Khonde, Lipigya A. Taklikar

Supervision: Vaibhav M. Gawande, Vijay Y. Karadbhaje, Ruta D. Khonde, Lipigya A. Taklikar

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request.

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