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CONCEPTS OF NANO EMULSION BASED DELIVERY SYSTEM

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Abstract: Nanoemulsions are advanced colloidal drug delivery systems consisting of two immiscible liquids stabilized by surfactants and co-surfactants, with droplet sizes typically ranging from 20 to 200 nm. Their nanoscale dimensions provide a large interfacial surface area, resulting in improved drug solubilization, enhanced stability, and increased bioavailability compared with conventional emulsions. Nanoemulsions have emerged as promising carriers for the delivery of poorly water-soluble drugs, particularly Biopharmaceutics Classification System (BCS) Class II and IV compounds. These systems enhance drug absorption, facilitate lymphatic transport, reduce first-pass metabolism, and improve therapeutic efficacy in oral, topical, and other delivery routes. This review highlights the fundamental principles of nanoemulsion-based drug delivery systems, including their classification into oil-in-water (O/W), water-in-oil (W/O), and bicontinuous nanoemulsions. The role of formulation components such as oils, surfactants, co-surfactants, and hydrophilic–lipophilic balance (HLB) values in achieving optimal stability and performance is discussed. Various preparation techniques, including high-pressure homogenization, ultrasonication, microfluidization, spontaneous emulsification, and phase inversion methods, are reviewed with respect to their advantages and limitations. The significance of pseudo-ternary phase diagrams in formulation optimization and nanoemulsion region identification is also addressed. Furthermore, key characterization parameters such as droplet size, polydispersity index, zeta potential, morphology, viscosity, drug entrapment efficiency, in vitro drug release, and stability studies are summarized. Overall, nanoemulsions represent a versatile and effective platform for enhancing drug delivery and improving therapeutic outcomes in modern pharmaceutical applications.

Keywords: *Nanoemulsions, Drug Delivery Systems, Bioavailability Enhancement, Surfactants and Co-surfactants, Pseudo-Ternary Phase Diagram, Nanoemulsion Characterization.*

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INTRODUCTION

Nanoemulsions are advanced colloidal drug delivery systems composed of two immiscible liquids stabilized by surfactants and co-surfactants. The system contains nanosized droplets that exhibit unique physicochemical properties compared to conventional emulsions. Due to their small droplet size and large interfacial surface area, nanoemulsions demonstrate enhanced stability, transparency, and improved drug dissolution characteristics [1,2]. The droplet size of nanoemulsions generally ranges from 20–200 nm, although slight variations may occur depending on formulation composition and preparation method [2].

The nanoscale droplet size provides a larger surface area for drug dissolution, resulting in improved drug absorption and bioavailability. Nanoemulsions also exhibit greater resistance to creaming, sedimentation, and coalescence than conventional macroemulsions. It is important to distinguish nanoemulsions from microemulsions. Microemulsions are thermodynamically stable systems formed spontaneously due to ultra-low interfacial tension, whereas nanoemulsions require external energy input during preparation and remain kinetically stable systems [3]. Moreover, microemulsions generally require higher concentrations of surfactants, limiting their pharmaceutical applicability [3].

The growing interest in nanoemulsion-based drug delivery systems is largely attributed to the increasing number of poorly water-soluble drug molecules in pharmaceutical development. Many newly discovered drugs belong to Biopharmaceutics Classification System

(BCS) Class II and IV, exhibiting poor aqueous solubility and low bioavailability. Nanoemulsions overcome these limitations by enhancing drug solubilization, facilitating membrane permeation, promoting lymphatic transport, and reducing first-pass metabolism, thereby improving therapeutic outcomes [3,4].

Nanoemulsions are particularly effective for oral and topical drug delivery applications. In oral delivery, oil-in-water (O/W) nanoemulsions improve gastrointestinal solubilization and facilitate rapid absorption of lipophilic drugs due to their extensive surface area and enhanced dispersion in gastrointestinal fluids [4]. In topical applications, nanoemulsions improve drug penetration through the stratum corneum, enhance skin hydration, and increase drug retention within the skin, making them suitable carriers for anti-inflammatory, antimicrobial, and wound-healing agents [5]. Thus, nanoemulsions represent a versatile and efficient platform for both oral and topical drug delivery.

Types of Nanoemulsions

Nanoemulsions are generally classified according to the arrangement of oil and water phases within the system. The structural organization significantly influences drug solubilization, release characteristics, and biological performance [6,7].

Oil-in-Water (O/W) Nanoemulsions

In oil-in-water nanoemulsions, tiny oil droplets are dispersed throughout a continuous aqueous phase. These systems are the most commonly used nanoemulsions in pharmaceutical applications, particularly for oral and topical drug delivery. Their aqueous external phase provides excellent compatibility with physiological fluids [6].

Lipophilic drugs are solubilized within the oil droplets, while the surrounding aqueous medium facilitates their dispersion and absorption. The small droplet size increases the available surface area, enhancing dissolution and absorption rates. Following oral administration, O/W nanoemulsions improve gastrointestinal solubilization and may facilitate lymphatic transport, thereby reducing hepatic first-pass metabolism. In topical delivery, these systems enhance skin penetration while providing a non-greasy and patient-friendly formulation [8].

Water-in-Oil (W/O) Nanoemulsions

Water-in-oil nanoemulsions consist of water droplets dispersed within a continuous oil phase. These systems are particularly useful for delivering hydrophilic drugs, where the aqueous phase serves as the drug reservoir.

The external oil phase provides an occlusive effect on the skin, reducing transepidermal water loss and increasing drug residence time at the application site [6]. Consequently, W/O nanoemulsions are commonly employed in dermatological and cosmetic formulations. However, their use in oral drug delivery remains limited because of palatability concerns and reduced compatibility with gastrointestinal fluids.

Bicontinuous Nanoemulsions

Bicontinuous nanoemulsions contain interpenetrating networks of oil and water phases, where neither phase completely surrounds the other. Instead, both phases form continuous interconnected domains throughout the system [6,8].

These structures are formed under specific surfactant concentrations and composition ratios. Bicontinuous nanoemulsions are capable of simultaneously incorporating hydrophilic and lipophilic drugs, making them attractive for combination therapy approaches. Despite these advantages, their pharmaceutical applications remain limited compared to O/W nanoemulsions due to formulation complexity and stability challenges [6,8].

Components of Nanoemulsion Systems

The composition of nanoemulsions significantly influences droplet size, stability, drug-loading capacity, and biological performance. Key formulation components include the oil phase, surfactants, co-surfactants, and hydrophilic-lipophilic balance (HLB) considerations [6,7].

Oil Phase Selection

The oil phase acts as the primary reservoir for lipophilic drugs and plays a critical role in determining drug loading and bioavailability. Selection of an appropriate oil phase is based on several factors, including:

- High drug solubility in oil
- Digestibility and metabolic fate
- Ability to enhance lymphatic transport
- Regulatory and safety considerations

Commonly used oils include medium-chain triglycerides (MCTs), long-chain triglycerides (LCTs), oleic acid, ethyl oleate, and isopropyl myristate. Medium-chain triglycerides are rapidly digested, whereas long-chain triglycerides are more effective in promoting lymphatic transport and reducing first-pass metabolism [6].

Oil viscosity also affects droplet formation during emulsification. Oils with lower viscosity generally produce smaller droplets because they are more easily disrupted during homogenization processes [7,8].

Role of Surfactants

Surfactants are essential components that reduce interfacial tension between oil and water phases, facilitating the formation of nanosized droplets. These molecules adsorb at the oil–water interface and form a protective layer around droplets, preventing coalescence and Ostwald ripening [9].

Nonionic surfactants are widely preferred in pharmaceutical nanoemulsions because of their superior safety profile and compatibility with biological systems. Their major advantages include:

- Lower toxicity
- Greater stability over a broad pH range
- Reduced irritation potential

Commonly used nonionic surfactants include polysorbates (Tween series), sorbitan esters (Span series), and polyoxyl castor oil derivatives (Kolliphor® series) [9].

Hydrophilic–Lipophilic Balance (HLB) Value

The Hydrophilic–Lipophilic Balance (HLB) value is an important criterion for selecting suitable surfactants in nanoemulsion formulations. The HLB system indicates the relative affinity of a surfactant toward water and oil phases.

- HLB 8–18 → Suitable for Oil-in-Water (O/W) nanoemulsions
- HLB 3–6 → Suitable for Water-in-Oil (W/O) nanoemulsions

Selection of an appropriate HLB value is critical for obtaining stable nanoemulsions with optimal droplet size distribution and long-term stability [6,9].

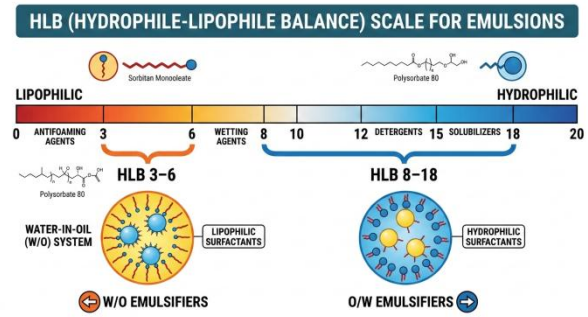

Figure 01: Hydrophile – Lipophile Balance

Stability begins when the oil phase meets its ideal surfactant match. Wrong numbers? Droplets break apart, layers flip - disorder takes over.

CO-SURFACTANTS

Working alongside main surfactants, co-surfactants help lower surface tension even more while making the boundary layer more pliable. Their presence boosts Nanoemulsion stability, Drug solubilization, Spontaneous emulsification and Reduction in required surfactant concentration. Alcohol like ethanol often shows up alongside propylene glycol when mixing surfactants. One might also find PEG 400 doing similar work in these blends. Then there is Transcutol®, a known helper in such formulas. Each brings something slightly different to the mix, yet they share the role. Choices depend on what the final product needs to do.

Table 01: Common Oil, Surfactant And Co Surfactant Used In Nanoemulsion

Component	Examples	Common Application
Oils	Medium-chain triglycerides	Oral
	Oleic acid	Oral & topical
	Ethyl oleate	Oral
	Isopropyl myristate	Topical
Surfactants	Tween 80	O/W nanoemulsion
	Tween 20	O/W systems
	Span 80	W/O systems
	Kolliphor EL	Oral formulations
Co-surfactants	Ethanol	Spontaneous emulsification
	Propylene glycol	Topical
	PEG 400	Oral
	Transcutol®	Solubilizer

METHODOLOGY

Aqueous Titration Method

Water-based titration plays a key role in spotting where nanoemulsions form when new mixtures are being developed. Starting with mixing small portions, researchers map out how oil, blended surfactants, and water interact. One drop at a time reveals boundaries where stable droplets emerge naturally [10]. These patterns help outline working zones on simplified three-part charts. Often, clarity comes only after repeated additions shift the balance. Through gradual change, effective ratios become visible without guesswork. Precision hides in the slow progression of measured steps [11].

A steady drip of water slips into blended oil and Smix, stirred without pause. As liquid flows in, shifts ripple through - guided by how tightly surfactants pack and bend between phases [10,12]. Once enough surfactant eases surface resistance, clarity emerges. The mix clears, turning smooth, uniform, tiny droplets suspended like glass [11–13].

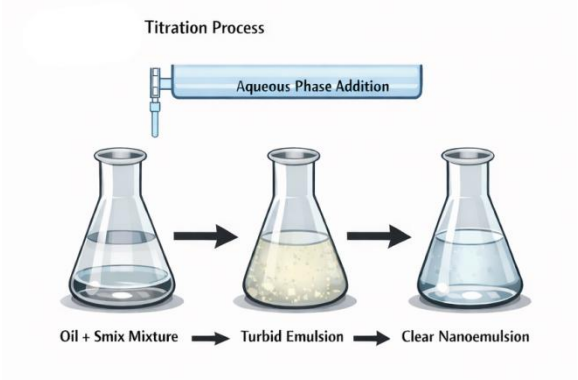

Figure 02: Titration Process

IDENTIFICATION OF NANOEMULSION REGION

Transparent and low-viscosity systems generally indicate the formation of nanosized droplets within the formulation. In contrast, cloudy appearance, turbidity, or phase separation suggests the presence of larger droplets or unstable systems. Formulations that remain transparent are selected, and their compositions are

plotted on triangular phase diagrams to identify the nanoemulsion region [14–16].

The aqueous titration method is widely used because it is simple, reproducible, and requires minimal instrumentation. However, visual transparency alone is insufficient to confirm nanoemulsion formation. Additional characterization studies are necessary to verify the existence of nanosized droplets and evaluate formulation stability. These include:

- Droplet size analysis
- Polydispersity index (PDI) determination
- Stability assessment
- Zeta potential measurement

The use of phase diagrams helps reduce extensive trial-and-error experimentation by systematically organizing formulation compositions. Nevertheless, confirmation of nanoemulsion formation requires analytical characterization beyond visual observation [17].

METHODS OF PREPARATION

The preparation method significantly influences droplet size, size distribution, stability, and drug release characteristics of nanoemulsions. Based on the energy required during formation, nanoemulsion preparation techniques are broadly classified into:

- High-energy methods
- Low-energy methods

High-energy methods utilize mechanical forces to break larger droplets into nanoscale droplets, whereas low-energy methods rely on the physicochemical properties of formulation components and spontaneous interfacial phenomena [18].

HIGH-ENERGY METHODS

High-energy techniques employ external mechanical energy to generate nanosized droplets. These methods are extensively used in pharmaceutical manufacturing due to their reproducibility and scalability [19].

HIGH-PRESSURE HOMOGENIZATION

High-pressure homogenization is one of the most commonly employed techniques for nanoemulsion preparation. In this method, a coarse emulsion is forced through a narrow gap under extremely high pressure, typically ranging from 500 to 5000 psi. Intense turbulence, cavitation, and shear forces break large droplets into nanosized droplets [19].

ADVANTAGES

- Produces very small droplet sizes Uniform droplet distribution
- Suitable for large-scale production
- Widely used for oral and parenteral formulations

Limitations

- High energy consumption
- Heat generation during processing
- Possible degradation of thermolabile drugs

Multiple homogenization cycles are often required to achieve a narrow droplet size distribution [19].

ULTRASONICATION

Ultrasonication utilizes high-frequency sound waves, typically above 20 kHz, to generate cavitation bubbles within the liquid medium. The collapse of these bubbles produces intense localized forces that break larger droplets into nanosized droplets.

Advantages

- Simple laboratory-scale technique
- Produces small droplet sizes efficiently
- Relatively easy operation

Limitations

- Difficult to scale up for industrial production
- Heat generation during prolonged sonication
- Potential degradation of heat-sensitive compounds

Ultrasonication is frequently employed during formulation development and optimization studies.

MICROFLUIDIZATION

Microfluidization involves forcing the emulsion through microchannels under high pressure. Opposing fluid streams collide within interaction chambers, producing intense shear forces that reduce droplet size.

ADVANTAGES

- Produces highly uniform droplets
- Narrow size distribution
- Enhanced physical stability
- Suitable for pharmaceutical and nutraceutical formulations

LIMITATIONS

- Expensive equipment
- Higher operational costs compared with conventional methods

Microfluidization is widely used for the production of highly stable nanoemulsions [20].

LOW-ENERGY METHODS

Low-energy methods utilize the intrinsic physicochemical properties of formulation components to generate nanoemulsions. These methods require significantly less external energy and rely on changes in composition or temperature [21].

Phase Inversion Temperature (PIT) Method

The PIT method is based on the temperature-dependent behavior of nonionic surfactants. At lower temperatures, surfactants exhibit greater affinity for water, whereas at elevated temperatures they become more lipophilic.

At the phase inversion temperature, the emulsion undergoes a transition between:

- Oil-in-water (O/W) systems
- Water-in-oil (W/O) systems

Rapid cooling at the inversion point results in the formation of fine nanosized droplets [22].

Advantages

- Low energy requirement
- Produces small droplet sizes
- Suitable for stable formulations

Limitations

- Not suitable for heat-sensitive drugs
- Requires precise temperature control

PHASE INVERSION COMPOSITION (PIC) METHOD

In the PIC method, the composition of the formulation is gradually altered while maintaining a constant temperature. Typically, water is added progressively to an oil–surfactant mixture.

At a critical composition, phase inversion occurs, leading to the spontaneous formation of nanosized droplets [23].

Advantages

- Precise control of droplet size
- Simple laboratory-scale preparation
- Low energy consumption

Limitations

- Limited scalability
- Requires careful optimization of composition

SPONTANEOUS EMULSIFICATION

Spontaneous emulsification occurs when an oil phase containing surfactant is mixed with an aqueous phase under gentle agitation. Diffusion of solvent molecules across the interface generates interfacial turbulence, resulting in spontaneous droplet formation.

Advantages

- Simple and economical method
- Minimal energy requirement
- Suitable for thermolabile drugs

Limitations

- Higher surfactant concentration required
- Limited formulation flexibility
- Selection of an appropriate preparation method depends on several factors:
- Drug stability
- Desired droplet size
- Scale-up requirements
- Production cost
- Regulatory considerations

PSEUDO-TERNARY PHASE DIAGRAM

Pseudo-ternary phase diagrams are valuable tools used to identify the composition ranges that produce stable nanoemulsions. These diagrams illustrate the interactions among oil, surfactant–co-surfactant mixture (Smix), and water, thereby reducing the need for extensive empirical experimentation [1,24].

CONCEPT AND PRINCIPLE

A ternary phase diagram is a triangular graphical representation used to describe the phase behavior of systems containing three components. In nanoemulsion formulation studies, a pseudo-ternary phase diagram is employed because the surfactant and co-surfactant are considered together as a single pseudo-component known as Smix [12].

The three corners of the triangular diagram represent:

- Oil phase
- Surfactant–co-surfactant mixture (Smix)
- Aqueous phase (water)

Each point within the triangle corresponds to a specific composition of these three components. By preparing formulations with varying component ratios and observing their physical appearance, researchers can identify the nanoemulsion region where stable, transparent, and homogeneous systems are formed [1,24].

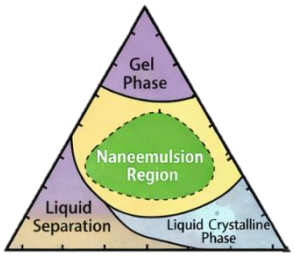

Figure 03: Ternary Phase Diagram Indicate the Nanoemulsion Rigion

The triangle contains points that represent specific ratios of three components which together total 100%.

CONSTRUCTION OF PSEUDO-TERNARY PHASE DIAGRAM

Pseudo-ternary phase diagrams are typically constructed using the aqueous titration method. Different weight ratios of surfactant and co-surfactant (e.g., 1:1, 2:1, 3:1) are prepared, and for each Smix ratio, mixtures of oil and Smix are titrated with water under controlled conditions [13].

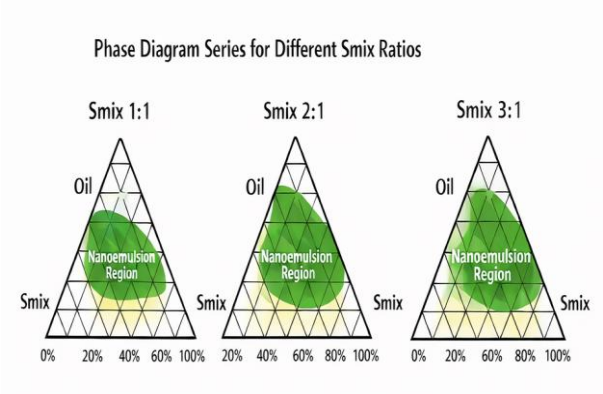

Figure 04: Shows Different Ratio of Smix Used In Nanoemulsion

The compositions at which clear, isotropic, and low-viscosity systems are formed are identified as nanoemulsion regions. These regions are plotted on triangular coordinates, and the nanoemulsion zone is shaded to distinguish it from emulsion, gel, or biphasic regions [13].

Separate diagrams are usually constructed for each Smix ratio to determine the optimal surfactant concentration that yields the maximum nanoemulsion area [16].

Interpretation of Phase Regions

Pseudo-ternary phase diagrams typically exhibit several regions:

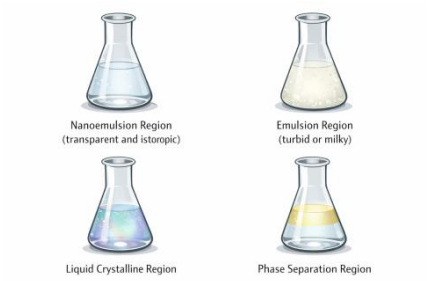

Figure 05: Shows Interpretation of Phase Regions

Interpretation of Phase Regions

Figure 5 illustrates the different phase regions observed in a pseudo-ternary phase diagram:

- Nanoemulsion region (transparent and isotropic)
- Emulsion region (turbid or milky)
- Liquid crystalline region
- Phase separation region
- A larger nanoemulsion region indicates greater formulation robustness and flexibility in component selection [10].
- The size and location of this region are influenced by several factors, including:
    - Oil polarity
    - Surfactant hydrophilic–lipophilic balance (HLB)
    - Temperature
    - Ionic strength [25]

SIGNIFICANCE IN ORAL AND TOPICAL NANOEMULSIONS

For oral nanoemulsions, pseudo-ternary phase diagrams assist in selecting compositions that maximize drug solubilization and enhance gastrointestinal absorption [26]. These diagrams also help identify self-emulsifying regions suitable for lipid-based drug delivery systems.

For topical nanoemulsions, phase diagrams aid in selecting formulations that provide:

- Appropriate viscosity
- Optimal droplet size
- Enhanced skin permeation
- Improved physical stability

Thus, pseudo-ternary phase diagrams serve as valuable preformulation tools in nanoemulsion research and development [24].

CHARACTERIZATION OF NANOEMULSIONS

Comprehensive characterization of nanoemulsions is essential to evaluate their physicochemical properties, stability, and suitability as drug delivery systems. Since nanoemulsions are kinetically stable systems, several parameters must be assessed to ensure their effectiveness and long-term stability. Characterization studies provide information regarding droplet size, surface charge, morphology, rheological behavior, drug loading, drug release, and storage stability [10,12,27].

DROPLET SIZE AND POLYDISPERSITY INDEX (PDI)

Droplet size is one of the most important parameters influencing nanoemulsion stability, drug release, and bioavailability. Pharmaceutical nanoemulsions typically exhibit droplet sizes ranging from 20 to 200 nm. Smaller droplets provide a larger interfacial surface area, enhancing drug dissolution and absorption, particularly for poorly water-soluble drugs [28].

Droplet size and size distribution are commonly measured using:

• Dynamic Light Scattering (DLS)
• Photon Correlation Spectroscopy (PCS)

The **Polydispersity Index (PDI)** indicates the uniformity of droplet size distribution.

Interpretation of PDI values:

• PDI < 0.3 → Uniform and monodisperse system
• PDI 0.3–0.5 → Moderate size distribution
• PDI > 0.5 → Broad size distribution and potential instability

Monitoring droplet size during storage helps identify instability phenomena such as:

•Coalescence
•Aggregation
• Ostwald ripening [28]

An increase in droplet size over time may indicate physical instability within the nanoemulsion system.

ZETA POTENTIAL

Zeta potential represents the electrical charge present at the droplet surface and is a key indicator of nanoemulsion stability. It is measured using electrophoretic light scattering techniques, where the movement of charged droplets under an electric field is analyzed.

General stability criteria:

• Greater than +30 mV → Good stability
• Less than –30 mV → Good stability
• Between ±20 mV → Moderate stability

In ionic surfactant-based nanoemulsions, electrostatic repulsion prevents droplet aggregation. However, nonionic surfactants primarily stabilize nanoemulsions through steric hindrance rather than electrostatic interactions [2,16,29].

Factors affecting zeta potential include:

- Surfactant adsorption
- pH changes
- Ionic strength of the medium
- Storage conditions

Changes in zeta potential during storage may indicate alterations in formulation stability.

MORPHOLOGICAL CHARACTERIZATION (TEM/SEM)

Morphological studies provide direct visualization of droplet shape, size, and distribution.

TRANSMISSION ELECTRON MICROSCOPY (TEM)

TEM is widely used for nanoemulsion characterization because it offers high-resolution imaging at the nanoscale level.

TEM analysis typically confirms:

- Spherical droplet morphology
- Uniform size distribution
- Absence of aggregation

SCANNING ELECTRON MICROSCOPY (SEM)

SEM is generally performed on freeze-dried nanoemulsion samples and provides information regarding:

- Surface morphology
- Structural uniformity
- Surface texture

CRYOGENIC TRANSMISSION ELECTRON MICROSCOPY (CRYO-TEM)

Cryo-TEM enables observation of nanoemulsions in their native hydrated state by rapidly freezing the sample before imaging.

Advantages of Cryo-TEM:

- Prevents drying artifacts
- Preserves native droplet structure
- Provides accurate morphological information
- Morphological studies complement droplet size measurements and help identify:
- Aggregation
- Flocculation
- Structural deformation

VISCOSITY AND PH DETERMINATION

Viscosity Measurement

Viscosity significantly influences nanoemulsion stability, spreadability, and drug release characteristics.

Most oil-in-water nanoemulsions exhibit Newtonian flow behavior due to their relatively low internal phase volume [6].

Viscosity is commonly measured using:

- Brookfield rotational viscometer

Importance of viscosity:

- Reduces creaming and sedimentation
- Improves physical stability
- Influences topical spreadability
- Affects drug release rate

Higher viscosity generally restricts droplet movement and enhances formulation stability.

pH Measurement

pH evaluation is important to ensure:

- Drug stability
- Physiological compatibility
- Patient safety

For topical formulations, pH is generally maintained within the range of:

- pH 5–6 (compatible with skin physiology)

For oral formulations, pH influences:

- Drug solubility
- Drug dissolution
- Absorption characteristics [30]

Drug Content and Entrapment Efficiency

Drug content analysis ensures uniform drug distribution throughout the nanoemulsion formulation.

Common analytical methods include:

- UV–Visible Spectrophotometry
- High-Performance Liquid Chromatography (HPLC)

Entrapment Efficiency (EE%)

Entrapment efficiency indicates the percentage of drug successfully incorporated within the internal phase of the nanoemulsion.

Entrapment Efficiency (%) =

$$\frac{\text{Total Drug} - \text{Free Drug}}{\text{Total Drug}} \times 100$$

High entrapment efficiency indicates:

- Effective drug solubilisation
- Reduced drug crystallization
- Improved formulation performance
- Entrapment efficiency is influenced by:
- Drug lipophilicity
- Oil phase composition
- Surfactant concentration
- Preparation method [30].

IN VITRO DRUG RELEASE STUDIES

In vitro release studies evaluate the rate and extent of drug release from nanoemulsion systems.

Commonly used methods include:

- Dialysis bag method
- Franz diffusion cell method
- USP dissolution apparatus

These techniques provide information regarding release kinetics and drug availability [1,25,30,31].

Nanoemulsions generally exhibit faster drug release compared with conventional suspensions due to:

- Smaller droplet size
- Increased surface area
- Improved drug solubilization

Drug release profiles may follow various kinetic models such as:

- Zero-order kinetics
- First-order kinetics
- Higuchi model
- Korsmeyer–Peppas model

Stability Studies

Stability evaluation is essential to ensure the long-term performance and shelf-life of nanoemulsion formulations.

Accelerated Stability Testing

Common stability studies include:

- Centrifugation test
- Heating–cooling cycles
- Freeze–thaw cycles

These tests help identify formulations susceptible to physical instability.

Long-Term Stability Studies

Long-term stability studies are performed under controlled conditions according to ICH guidelines.

Parameters monitored during storage include:
• Droplet size
• Polydispersity index
• Zeta potential
• Viscosity
• pH
• Drug content

COMMON INSTABILITY MECHANISMS

Coalescence
• Fusion of droplets into larger droplets
Flocculation
• Aggregation of droplets without fusion
Creaming
• Upward migration of dispersed droplets
Ostwald Ripening
• Growth of larger droplets at the expense of smaller droplets
Monitoring these instability mechanisms helps ensure formulation consistency during storage, transportation, and clinical use [32].

CONCLUSION

Nanoemulsions have emerged as promising drug delivery systems due to their ability to improve the solubility, stability, bioavailability, and therapeutic efficacy of poorly water-soluble drugs. Their nanoscale droplet size, large interfacial surface area, and versatility make them suitable for both oral and topical applications. Successful formulation depends on appropriate selection of oils, surfactants, co-surfactants, and preparation methods, while pseudo-ternary phase diagrams aid in formulation optimization. Comprehensive characterization, including droplet size, PDI, zeta potential, morphology, viscosity, drug release, and stability studies, is essential to ensure formulation quality and performance. Overall, nanoemulsions represent an effective and adaptable platform for advanced pharmaceutical drug delivery.

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CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

All authors are contributed equally

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