www.hsmc.gr/en/pharmakeftiki-journal/

PHARMAKEFTIKI, 37, 2S, 2025 | 488-491 REVIEW

https://doi.org/10.60988/p.v37i2S.272

Micro- and nano-emulsion drug delivery systems: a review

Suhad H. Alzubaidy[1,*], Shafq Al-Azzawi[2]

[1]College of Pharmacy, University of Babylon, Hillah, Iraq
[2]Department of Clinical Pharmacy, College of Pharmacy, University of Babylon, Hillah, Iraq

KEY WORDS:
emulsion; micro-emulsion; nano-emulsion; drug delivery system; dispersion

ARTICLE INFO:
Received: January 07, 2025
Revised: February 02, 2025
Accepted: February 13, 2025
Available online: October 10, 2025

ABSTRACT

Interest in micro- and nano-emulsions has steadily grown over recent decades, owing to their distinctive physicochemical properties and expanding utility in the medical field. These nano-scaled formulations – typically ranging from tens to several hundreds of nanometres – offer considerable potential for pharmaceutical applications. This review provides a structured overview of recent advances in micro- and nano-emulsion-based drug delivery systems. It begins by defining emulsions and their classifications, then delineates the distinctions between conventional emulsions and their micro/nano counterparts, with particular emphasis on the differences between micro- and nano-emulsions. The review further examines the principal advantages and limitations of these systems relative to other pharmaceutical formulations. Finally, it highlights their emerging roles in targeted drug delivery, underscoring their promise as versatile platforms for tissue-specific therapeutic interventions.

1. Introduction

Emulsions are defined as mixtures of two immiscible liquids, wherein spherical droplets constitute the dispersed phase and the surrounding liquid forms the continuous phase[1]. Notable advancements have emerged in nanotechnology, particularly in the development of particles smaller than 1 μm. Nanoparticles (comparable in size to cellular organelles) have garnered significant attention[2]. Micro- and nano-emulsions are liquid-based formulations that offer considerable promise for enhancing drug bioavailability across diverse therapeutic domains. Their ability to improve solubility, stability, and targeted delivery renders them valuable tools in the design of novel pharmaceutical products[3].

*** CORRESPONDING AUTHOR:**
Suhad H. Alzubaidy,
College of Pharmacy,
University of Babylon,
Hillah, Iraq; e-mail:
pha559.suhad.a@uobabylon.edu.iq

PHARMAKEFTIKI, 37, 2S, 2025 | 488-491

2. Emulsion

An emulsion is a biphasic system in which one liquid phase is dispersed as fine droplets within another immiscible liquid phase[1]. These droplets are typically invisible to the naked eye, and emulsions are often classified as colloidal systems. As the droplet size decreases, the emulsion's appearance transitions from milky white to translucent[2]. Although thermodynamically unstable, emulsions can be stabilized by emulsifying agents. The dispersed phase – also termed the "internal" or "discontinuous" phase – is suspended within the dispersion medium, known as the "external" or "continuous" phase. The emulsifying agent occupies the interfacial region and is referred to as the "intermediate" phase or simply "interphase"[1].

3. Micro- and nano-emulsion

The conceptual origins of nano-emulsions trace back to early 20th-century studies into colloidal systems. Initial research focused on macro- and micro-emulsions, laying the groundwork for the nano-emulsion development[3]. Micro- and nano-emulsions are nanometric dispersions comprising an oil phase, a water phase, and surfactants. Despite their compositional similarities, they exhibit distinct physicochemical properties that facilitate differentiation and classification[4].

These systems typically contain droplets smaller than 1 μm. Micro-emulsions are thermodynamically stable dispersions with droplet sizes ranging from 100 to 400 nm, whereas nano-emulsions are thermodynamically unstable but kinetically stable, with droplet sizes between 1 and 100 nm. Nano-emulsions often require cosurfactants to overcome their elevated free energy and achieve stability[2]. Unlike micro-emulsions, nano-emulsions maintain prolonged physical consistency and resist aggregation and flocculation[3].

Nano-emulsion technology has found applications in various sectors, including food science, biomedicine, and cosmetics. In skin bioengineering, nano-emulsions have emerged as effective carriers for therapeutic agents and cosmetic compounds, addressing challenges related to penetration and absorption[2].

4. Differences between micro- and nano-emulsions

Although micro- and nano-emulsions share similar components, they differ significantly in droplet size and thermodynamic behavior. As already stated above, micro-emulsions typically exhibit droplet sizes of 100–400 nm, while nano-emulsions range from 1 to 100 nm[2]. The critical differentiator is system free energy, which influences both formulation and stability. Micro-emulsions are thermodynamically stable and can form spontaneously; however, external energy inputs – such as heating or magnetic stirring – are often employed in order to facilitate the mixing of water, oil, and surfactant. In contrast, nano-emulsions are energetically unfavourable and require substantial external energy so as to overcome the free energy barrier between immiscible phases and achieve colloidal dispersion. This disparity in free energy also impacts long-term stability[4].

5. Advantage and disadvantage of micro- and nano-emulsions

Micro- and nano-emulsions offer several advantages over conventional drug delivery systems. They enhance the bioavailability of hydrophobic pharmaceuticals[1], protect active compounds from degradation, and extend the shelf life of medications[3]. Their ability to safeguard drugs from oxidation and hydrolysis contributes to formulation stability, while their liquid dosage form improves patient adherence[5]. These systems are relatively easy to prepare and exhibit notable physicochemical stability[6]. Owing to their non-toxic and non-irritating nature, they are suitable for application to mucous membranes and skin[7]. Additionally, they can mask metallic and acrid flavours[3], and are amenable to oral administration when formulated with biocompatible surfactants. Micro- and nano-emulsions also serve as precursors in the fabrication of nanocapsules and nanospheres, thereby

PHARMAKEFTIKI, 37, 2S, 2025 | 488-491

facilitating efficient drug transport[7]. Their versatility allows for formulation into various dosage forms (including foams, creams, liquids, and sprays)[7], and they are applicable in both veterinary and human medicine[7]. Importantly, these systems can help circumvent hepatic first-pass metabolism, thereby improving systemic drug availability[3].

Despite these benefits, micro- and nano-emulsions present certain limitations. The production of small droplets necessitates specialized equipment and techniques, often involving costly procedures. The configuration of homogenizers – essential tools in emulsion formulation – is expensive, and production methods such as ultrasonication and microfluidization require substantial financial investment. Storage stability remains a challenge, and the high concentration of emulsifiers required for cosmetic applications further escalates production costs.

6. Applications

Micro- and nano-emulsions can be economically formulated into various pharmaceutical dosage forms, including creams, gels, foams, sprays, and aerosols. They support multiple routes of administration: oral, topical, intravenous, intrapulmonary, transnasal, and intraocular. Nano-emulsions are particularly effective in enhancing bioavailability for a range of therapeutic indications[3].

Micro-emulsions have demonstrated utility across diverse fields, including food science, coatings, lubricants, antimicrobial agents, drug delivery, nanoparticle synthesis, detergents, pesticides, biotechnology, and extraction processes. They also show promise in clinical diagnostics and disease management[6].

Numerous nano-emulsion-based drug delivery systems have been developed for medications such as anticancer, antimalarial, antipsychotic, antiglaucoma, and lipid-lowering agents[7]. For instance, nano-emulsion formulations of flurbiprofen (a poorly water-soluble drug) have improved its dissolution, solubility, stability, and bioavailability[5]. Similarly, nano-emulsions of piroxicam have enhanced its stability, release profile, and analgesic efficacy[8]. Mupirocin, a topical antibacterial agent limited by *in vivo* inactivation and plasma protein binding, has shown improved skin delivery when formulated as a nano-emulsion[9]. Finally, among the available nano-emulsion administration routes, topical and ocular delivery are gaining particular interest, alongside oral, nasal, and intravenous options[10].

7. Conclusion

Micro- and nano-emulsions exhibit superior pharmacokinetic profiles and targeting capabilities compared to conventional emulsions and other dosage forms. Their nanometric scale and favourable physicochemical properties support their expanding role in pharmaceutical applications, positioning them as promising platforms for advanced drug delivery.

Acknowledgements

We gratefully acknowledge the College of Pharmacy of the University of Babylon, and its Dean, Professor Dr Hussam W. Al-Humadi, for their support and for providing the opportunity to pursue this work.

Conflicts of interest

None exist.

ORCIDs

0009-0007-2811-4543 (S.H. Alzubaidy); 0000-0003-4243-0255 (S. Al-Azzawi)

PHARMAKEFTIKI, 37, 2S, 2025 | 488-491

References

1. Malode G.P., Chauhan S.A., Bartare S.A., Malode L.L., Manwar J.V., Bakal R.L. A critical review on nanoemulsion: advantages, techniques and characterization. *J. Appl. Pharm. Sci. Res.* 4(3), 6–12, 2021. DOI: 10.31069/japsr.v4i3.2
2. Souto E.B., Cano A., Martins-Gomes C., Coutinho T.E., Zielińska A., Silva A.M. Microemulsions and nanoemulsions in skin drug delivery. *Bioengineering (Basel)* 9(4), 158, 2022. DOI: 10.3390/bioengineering9040158
3. Preeti, Sambhakar S., Malik R., Bhatia S., Al Harrasi A., Rani C., *et al.* Nanoemulsion: an emerging novel technology for improving the bioavailability of drugs. *Scientifica (Cairo)* 2023, 6640103, 2023. DOI: 10.1155/2023/6640103
4. Pavoni L., Perinelli D.R., Bonacucina G., Cespi M., Palmieri G.F. An overview of micro- and nanoemulsions as vehicles for essential oils: formulation, preparation and stability. *Nanomaterials (Basel)* 10(1), 135, 2020. DOI: 10.3390/nano10010135
5. Mahmood H.S., Alaayedi M., Ghareeb M.M., Ali M.M.M. The enhancement solubility of oral flurbiprofen by using nanoemelsion as drug delivery system. *Int. J. Pharm. Res.* 12(s1), 1612–1619, 2020. DOI: 10.31838/ijpr/2020.SP1.248
6. Angelico R. Special Issue "Micro/Nano Emulsions: Smart Colloids for Multiple Applications". *Nanomaterials (Basel)* 12(21), 3734, 2022. DOI: 10.3390/nano12213734
7. Yadav V., Dhumal N., Borkar S. Nanoemulsion as novel drug delivery system: development, characterization and application. *Asian J. Pharm. Res. Devel.* 10(6), 120–127, 2022. DOI: 10.22270/ajprd.v10i6.1205
8. Gaber D.A., Alsubaiyel A.M., Alabdulrahim A.K., Alharbi H.Z., Aldubaikhy R.M., Alharbi R.S., *et al.* Nano-emulsion based gel for topical delivery of an anti-inflammatory drug: *in vitro* and *in vivo* evaluation. *Drug Des. Devel. Ther.* 17, 1435–1451, 2023. DOI: 10.2147/DDDT.S407475
9. Alhasso B., Ghori M.U., Conway B.R. Development of nanoemulsions for topical application of mupirocin. *Pharmaceutics* 15(2), 378, 2023. DOI: 10.3390/pharmaceutics15020378
10. Wilson R.J., Li Y., Yang G., Zhao C.X. Nanoemulsions for drug delivery. *Particuology* 64, 85–97, 2022. DOI: 10.1016/j.partic.2021.05.009

HOW TO CITE:
Alzubaidy S.H., Al-Azzawi S. Micro- and nano-emulsion drug delivery systems: a review. *Pharmakeftiki* 37(2s), 488-491, 2025. https://doi.org/10.60988/p.v37i2S.272