

Recent Trends in Nanoemulsion Technology for Topical Cosmetic Applications

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Abstract— Nanoemulsion technology has gained significant attention in recent years as an advanced approach for improving the performance of topical cosmetic formulations. Nanoemulsions are nanosized dispersions of oil and water stabilized by surfactants, offering advantages such as enhanced stability, improved solubility of active ingredients, and superior skin penetration. These properties make them highly suitable for modern cosmetic applications, including moisturizers, sunscreens, anti-aging, and anti-acne products.

This review highlights the fundamental aspects of nanoemulsions, including their composition, types, preparation methods, and key physicochemical characteristics. Special emphasis is given to recent trends such as green nanoemulsions, herbal-based systems, nanoemulsion-based gels and creams, targeted skin delivery, and stimuli-responsive formulations. These advancements focus on improving safety, sustainability, and overall product effectiveness.

In addition, the review discusses the applications, advantages, limitations, and regulatory considerations associated with nanoemulsion-based cosmetics. Despite certain challenges, continuous innovations and technological developments are expected to enhance their commercial viability. Overall, nanoemulsion technology represents a promising and evolving platform for the development of safe, effective, and consumer-friendly cosmetic products.

Index Terms— Nanoemulsion, Cosmetics, Technology, Formulation

I. INTRODUCTION

Nanotechnology has significantly changed the cosmetics industry in recent years, particularly with the creation of nanoemulsions.[1] Because of these systems' minuscule droplet size, active chemicals are better delivered to the skin, increasing the efficacy of cosmetic goods.[2] In contrast to traditional creams, nanoemulsions provide improved skin penetration,

stability, and a smooth, non-greasy feel, all of which boost consumer acceptance.[3] Natural chemicals, environmentally friendly surfactants, and sophisticated preparation techniques are becoming more and more popular in nanoemulsion-based formulations.[4] Nanoemulsions are being investigated extensively in goods such as anti-aging lotions, sunscreens, and moisturisers due to these benefits. The latest developments and trends in nanoemulsion technology for topical cosmetic applications are highlighted in this study.[5]

II. BASICS OF NANOEMULSIONS

With droplet sizes usually in the nanometre range, nanoemulsions are tiny dispersions of water and oil stabilized by surfactants. Because they can enhance the solubility, stability, and distribution of active substances via the skin, they are frequently utilized in cosmetic formulations.[6]

2.1 Definitions and Characteristics

With droplet sizes ranging from 20 to 200 nm, nanoemulsions are kinetically stable but thermodynamically unstable systems. Their large surface area and transparent or translucent appearance improve medication loading and skin penetration. Additionally, these systems have a smooth, non-greasy texture and good spreadability.[7]

2.2 Types of Nanoemulsion

Oil-in-water (O/W), where oil droplets are disseminated in water; water-in-oil (W/O), where water droplets are scattered in oil; and bicontinuous systems, where both the oil and water phases are interconnected, are the three primary categories of nanoemulsions. O/W nanoemulsions are the most widely used of these in cosmetic applications because of their superior skin feel and simplicity of use.[8]

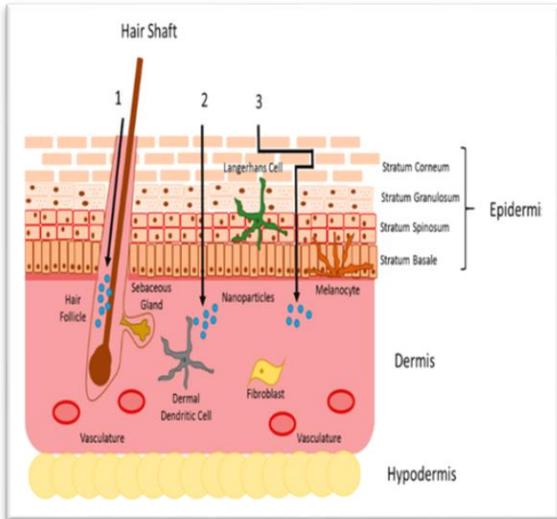


Fig. 1: Illustration of nanoparticle skin penetration pathways.[36]

III. COMPONENTS OF NANOEMULSIONS

Key components of nanoemulsions include water, oil, surfactants, and co-surfactants, all of which are crucial to the stability and effectiveness of the formulation.[9] While the water phase creates the continuous media, the oil phase aids in the dissolution of lipophilic active substances. While co-surfactants further improve the system's flexibility and stability, surfactants lower interfacial tension and stabilise the droplets.[10] A successful and aesthetically pleasing nanoemulsion formulation depends on the precise selection and ratio of these constituents.[11]

IV. METHODS OF PREPARATION

Specialised methods are used to create nanoemulsions, which aid in droplet size reduction and stability enhancement.[12] Depending on how much external energy is used during formulation, these techniques can be generally divided into high-energy and low-energy approaches.[13]

4.1 High-energy methods

High-energy techniques reduce droplets to nanoscale sizes using mechanical tools including ultrasonication, microfluidizers, and high-pressure homogenisers.[14] These methods are popular because they can create consistent and stable nanoemulsions, but they could need more energy and expensive equipment.[15]

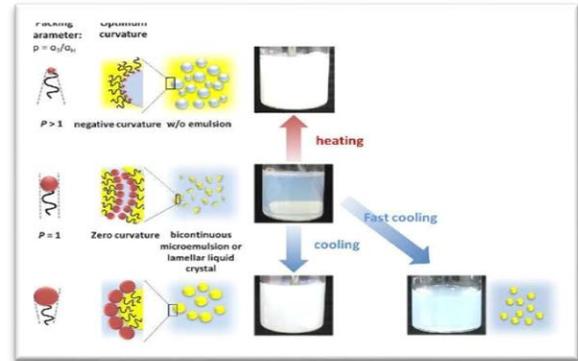


Fig. 2: Phase inversion temperature method of nanoemulsion preparation.[37]

4.2 Low energy methods

Low-energy techniques use the system's physicochemical characteristics, like phase inversion and spontaneous emulsification, to create nanoemulsions without requiring a lot of mechanical energy.[16] These methods are becoming more and more common in contemporary cosmetic formulations since they are economical, energy-efficient, and appropriate for heat-sensitive chemicals.[17]

V. CHARACTERISTICS OF NANOEMULSIONS

The exceptionally small droplet size of nanoemulsions typically between 20 and 200 nm provides a wide surface area and improves the transport of active substances through the skin.[18] They often have a translucent or transparent appearance, strong kinematic stability, and resistance to flocculation, coalescence, and creaming.[19] Additionally, the smooth texture, excellent spreadability, and non-greasy feel of nanoemulsions are desired cosmetic qualities that increase consumer acceptability.[20] They are ideal for topical cosmetic applications due to their capacity to improve bioavailability and increase the solubility of poorly water-soluble substances.[21]

VI. RECENT TRENDS IN NANOEMULSION TECHNOLOGY

The performance, sustainability, and safety of cosmetic formulations are the main goals of recent developments in nanoemulsion technology.[22] To satisfy consumer and regulatory demands, modern

strategies place a strong emphasis on the use of environmentally friendly ingredients, improved delivery systems, and creative formulation processes.[23]

6.1 Green Nanoemulsions

Biodegradable, non-toxic, and eco-friendly oils and surfactants are used in green nanoemulsions. These formulations are particularly sought after in sustainable cosmetic development since they enhance safety and lessen their negative effects on the environment.[24]

6.2 Herbal/Plant Based Nanoemulsions

Aloe vera, neem, and curcumin are examples of plant-derived active compounds used in herbal nanoemulsions. These systems improve natural chemicals' stability and skin penetration, boosting their efficacy in cosmetic applications.[25]

6.3 Nanoemulsion based gels and creams

Gels and creams are increasingly using nanoemulsions to enhance their texture, spreadability, and visual appeal. Better skin feels, quicker absorption, and improved active ingredient delivery are all provided by these formulations.[26]

6.4 Targeted Skin Delivery Systems

Cutting-edge nanoemulsion systems are made to target specific skin layers with active chemicals. This tailored distribution guarantees regulated release of cosmetic actives, increases efficacy, and minimises negative effects.[27]

6.5 Stimuli Responsive Nanoemulsions

In reaction to external stimuli like pH, temperature, or light, stimuli-responsive nanoemulsions are made to release active components. These intelligent solutions provide a bright future for cosmetic technology by providing site-specific and regulated activity.[28]

VII. APPLICATIONS IN COSMETICS

Because they can improve the distribution and efficacy of active substances, nanoemulsions are frequently utilised in cosmetic compositions. They operate better than traditional products because of their small droplet size, which enhances skin penetration.[29] Products including moisturisers, sunscreens, anti-aging creams, and anti-acne formulas frequently

contain them. Additionally, nanoemulsions enhance cosmetic products' texture, spreadability, and overall visual attractiveness by giving them a smooth, non-greasy feel that boosts customer satisfaction.[30]

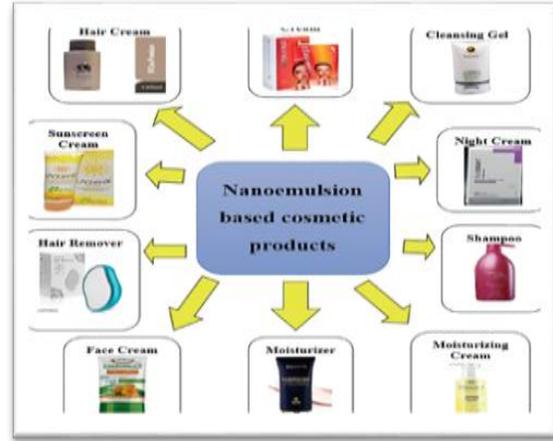


Fig. 3: Different nanoemulsion based cosmetic products.

VIII. ADVANTAGES AND LIMITATIONS

In comparison to traditional methods, nanoemulsions have a number of benefits for cosmetic formulations, such as improved skin penetration, increased solubility of active chemicals, and improved stability.[31] They also provide desirable aesthetic properties such as smooth texture, high spreadability, and a non-greasy feel, which improve user acceptance and product performance.

Nevertheless, nanoemulsions have certain drawbacks, such as the requirement for high surfactant concentrations, which in certain situations may irritate the skin. Furthermore, the formulation process may be complicated and call for specialised tools, which raises the cost of manufacture. Concerns about nanoparticles' long-term stability and regulations continue to be significant obstacles.[32]

IX. FUTURE PERSPECTIVES

With continuous research aimed at creating safer, more efficient, and greener formulations, nanoemulsion technology in cosmetics has a very bright future.[33] The future generation of cosmetics is anticipated to be driven by innovations including the use of natural chemicals, biodegradable surfactants,

and energy-efficient preparation techniques.[34] Furthermore, cutting-edge methods like intelligent delivery systems, customised skincare, and incorporating AI into formulation creation are becoming more popular. These advancements are intended to improve product performance, guarantee focused action, and satisfy changing consumer and regulatory requirements.[35]

X. CONCLUSION

Nanoemulsion technology has emerged as a highly promising method in the realm of topical cosmetic applications, because to its capacity to improve stability, skin penetration, and aesthetic characteristics. Its potential in contemporary cosmetics has been further increased by the use of natural substances, eco-friendly components, and sophisticated formulation techniques. Innovation in this field is becoming increasingly important, as evidenced by recent trends including stimuli-responsive delivery, herbal-based systems, and green nanoemulsions. It is anticipated that ongoing research and technical developments will overcome some obstacles pertaining to cost, safety, and regulatory concerns.

All things considered, nanoemulsions are a major advancement in cosmetic science, providing efficient, secure, and user-friendly solutions for the creation of skincare products of the future.

REFERENCES

- [1] V. Gupta et al., "Nanotechnology in cosmetics and cosmeceuticals a review of latest advancements," *Gels*, vol. 8, no. 3, p. 173, 2022.
- [2] V. B. Patravale and S. D. Mandawgade, "Novel cosmetic delivery systems: An application update," *International Journal of Cosmetic Science*, vol. 30, no. 1, pp. 19–33, 2008.
- [3] E. Deveci, "Nanoemulsions in cosmetics: Enhancing efficacy and stability," *Journal of Dermatologic Science and Cosmetic Technology*, p. 100107, 2025.
- [4] F. Mustafa and M. Z. Hussein, "Synthesis and technology of nanoemulsion-based pesticide formulation," *Nanomaterials*, vol. 10, no. 8, p. 1608, 2020.
- [5] M. Hariharan et al., "A comprehensive review on current and future trends of nanoemulsions in modern cosmetics and pharmaceuticals," *International Journal of Advanced Science and Engineering*, vol. 11, no. 3, p. 4257, 2025.
- [6] E. B. Souto et al., "Microemulsions and nanoemulsions in skin drug delivery," *Bioengineering*, vol. 9, no. 4, p. 158, 2022.
- [7] S. Sajjadi, M. Zerfa, and B. W. Brooks, "Dynamic behaviour of drops in oil/water/oil dispersions," *Chemical Engineering Science*, vol. 57, no. 4, pp. 663–675, 2002.
- [8] L. Pavoni et al., "An overview of micro- and nanoemulsions as vehicles for essential oils: Formulation, preparation and stability," *Nanomaterials*, vol. 10, no. 1, p. 135, 2020.
- [9] N. Dhas et al., "Role of surfactants and co-surfactants in formulation of microemulsions," in *Pharmaceutical Microemulsions for Parenteral Delivery*. Apple Academic Press, 2025, pp. 57–90.
- [10] M. N. Yukuyama et al., "Nanoemulsion: Process selection and application in cosmetics a review," *International Journal of Cosmetic Science*, vol. 38, no. 1, pp. 13–24, 2016.
- [11] Preeti et al., "Nanoemulsion: An emerging novel technology for improving the bioavailability of drugs," *Scientifica*, vol. 2023, p. 6640103, 2023.
- [12] R. C. Santana, F. A. Perrechil, and R. L. Cunha, "High- and low-energy emulsifications for food applications: A focus on process parameters," *Food Engineering Reviews*, vol. 5, no. 2, pp. 107–122, 2013.
- [13] T. Chen et al., "Micronization and nanosizing of particles for an enhanced quality of food: A review," *Critical Reviews in Food Science and Nutrition*, vol. 58, no. 6, pp. 993–1001, 2018.
- [14] Qadir et al., "Critical steps and energetics involved in a successful development of a stable nanoemulsion," *Journal of Molecular Liquids*, vol. 214, pp. 7–18, 2016. Gohtani, Shoichi, and Waraporn Prasert. "Nano-emulsions; Emulsification using low energy methods." *Japan Journal of Food Engineering* 15.3 (2014): 119-130.
- [15] E. Karthikeyan and A. Priyadharshini, "Eco-efficient extraction techniques for biomedical materials: From solvent-free methods to

- assisted technologies,” *Biomedical Materials & Devices*, pp. 1–25, 2025.
- [16] E. B. Souto et al., “Microemulsions and nanoemulsions in skin drug delivery,” *Bioengineering*, vol. 9, no. 4, p. 158, 2022.
- [17] T. F. Tadros, *Emulsions: Formation, Stability, Industrial Applications*. Berlin, Germany: Walter de Gruyter GmbH & Co. KG, 2016.
- [18] Liakopoulou et al., “Comparative study between nanoemulsions and conventional emulsions as carriers of plant oils: Formulation approach, physicochemical properties, and in vitro and in vivo assessments for skin care application,” *Cosmetics*, vol. 12, no. 3, p. 102, 2025.
- [19] D. A. Safta, C. Bogdan, and M.-L. Moldovan, “SLNs and NLCs for skin applications: Enhancing the bioavailability of natural bioactives,” *Pharmaceutics*, vol. 16, no. 10, p. 1270, 2024.
- [20] N. H. Che Marzuki, R. A. Wahab, and M. A. Hamid, “An overview of nanoemulsion: Concepts of development and cosmeceutical applications,” *Biotechnology & Biotechnological Equipment*, vol. 33, no. 1, pp. 779–797, 2019.
- [21] D. H. Shastri, S. Gandhi, and H. Almeida, “Enhancing collaboration and interdisciplinary strategies for navigating innovative technologies and regulatory approvals in the cosmetic industry,” *Current Cosmetic Science*, vol. 3, no. 1, 2024.
- [22] Padole et al., “Green nanoemulsions for sustainable applications,” in *Green Engineering and Sustainable Technology: Tools and Techniques*. 2026, pp. 135–160.
- [23] H. Hazarika et al., “Nanoemulsion delivery of herbal products: Prospects and challenges,” in *Nano Medicine and Nano Safety: Recent Trends and Clinical Evidences*. 2020, pp. 267–288.
- [24] M. Miastkowska, A. Kulawik-Pióro, and M. Szczurek, “Nanoemulsion gel formulation optimization for burn wounds: Analysis of rheological and sensory properties,” *Processes*, vol. 8, no. 11, p. 1416, 2020.
- [25] R. Achagar et al., “A comprehensive review of essential oil–nanotechnology synergy for advanced dermocosmetic delivery,” *Cosmetics*, vol. 11, no. 2, p. 48, 2024.
- [26] M. R. I. Shishir et al., “Advances in smart delivery of food bioactive compounds using stimuli-responsive carriers: Responsive mechanism, contemporary challenges, and prospects,” *Comprehensive Reviews in Food Science and Food Safety*, vol. 20, no. 6, pp. 5449–5488, 2021.
- [27] N. B. Romes, R. A. Wahab, and M. A. Hamid, “The role of bioactive phytoconstituents-loaded nanoemulsions for skin improvement: A review,” *Biotechnology & Biotechnological Equipment*, vol. 35, no. 1, pp. 711–730, 2021.
- [28] F. E. Adagbon, *Physicochemical Properties of the Essential Oil*. M.S. thesis, University of Benin, 2025.
- [29] M. N. Yukuyama et al., “Nanoemulsion: Process selection and application in cosmetics—a review,” *International Journal of Cosmetic Science*, vol. 38, no. 1, pp. 13–24, 2016.
- [30] B. Alhasso, *Development and Characterisation of Nanoemulsion and Nanoemulgel Formulations for Topical Application of Mupirocin*. Ph.D. dissertation, University of Huddersfield, 2023.
- [31] R. D. Singh et al., “A review on green nanoemulsions for cosmetic applications with special emphasis on microbial surfactants as impending emulsifying agents,” *Journal of Surfactants and Detergents*, vol. 25, no. 3, pp. 303–319, 2022.
- [32] G. B. B. Nhani et al., “High-tech sustainable beauty: Exploring nanotechnology for the development of cosmetics using plant and animal by-products,” *Cosmetics*, vol. 11, no. 4, p. 112, 2024.
- [33] B. Shen et al., “The role of regulatory reforms, market changes, and technology development to make demand response a viable resource in meeting energy challenges,” *Applied Energy*, vol. 130, pp. 814–823, 2014.
- [34] A.-V. Weiß, “Hydrophilic drug delivery based on gelatin nanoparticles,” 2018.
- [35] Y. Nie et al., “Stability and bioactivity evaluation of black pepper essential oil nanoemulsion,” *Heliyon*, vol. 9, no. 4, 2023.