

EXPLORING THE ADVANCES IN NANO-FORMULATIONS FOR SKIN CARE APPLICATIONS

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ABSTRACT

The past several years has paid much attention to the incorporation of nanotechnology into skincare products because of its potential to revolutionize delivery active ingredients into the skin. Nanodispersion designs are precisely engineered nanoparticles at the nanoscale, offering unique benefits of stability enhancement, deepening penetration, and efficacy in skincare products. It enhances the absorption efficiency of such ingredients in the skin, so active ingredients will penetrate through several layers of skin to address problems like aging, acne, and hydration. The ways that nano-formulations enhance skincare are encapsulating sensitive molecules, protecting these against degradation, and then resulting in a controlled release over time. It does not only enhance the effectiveness of traditional cosmetic agents but also reduces irritation or side effects. There are many nano-formulations such as liposomes, polymeric nanoparticles, and SLN that facilitate the optimization of moisturizers, antioxidants, and other active agents in their delivery. Further tailoring of the formulations makes them even more effective and applicable to most skin types and conditions. It now goes beyond basic hydration and anti-aging with more specific skincare treatments such as acne, pigmentation, and barrier repair. Nano-formulations continue to evolve, and much is yet to be seen while addressing safety and regulatory issues related to these long-term effects of nano-formulated products. Topics discussed include principles underlining nano-formulations, the mechanisms driving efficacy, current, and potential applications in the skin care industry that give an all-around view of how nanotechnology is shaping the future of cosmetic and therapeutic skincare.

Keywords: Nano-formulations, nanotechnology, skin care, nanoparticles, active ingredients, skin penetration, cosmetic delivery systems, liposomes, polymeric nanoparticles, skin hydration, anti-aging, acne treatment, targeted delivery, controlled release, skin barrier.

I. INTRODUCTION

Being developed to increase the effectiveness on multifaceted broad ranges of concern, aging, dryness, acnes, pigmentation, recent innovations in the world of nanotechnology for the very first time, opened up the scope for efficiently and precisely formulating skincare products which carry active ingredients for the skin. With a groundbreaking use of ingredients between 1 to 100 nanometers as nanoparticle sizing, it facilitates ingredient delivery through penetration up to the dermis and thus closer to direct sustained contact in treating various forms of skin type or conditions. The use of technology here revolutionizes skin care applications as well, to deliver the desired result as varied skin needs exist among people.

One of the primary benefits of nano-formulations is that they enhance the stability and bioavailability of active ingredients. Most of the traditional skincare products contain rapidly degradable ingredients that deteriorate fast once exposed to air or light. Nano-formulations encapsulate such ingredients, thereby shielding them from environmental factors that might cause deterioration and ensuring the ingredient remains potent once applied to the skin. These nano-carriers deliver controlled and sustained release, meaning the longevity and potency of products improve and tackle concerns like hydration, anti-aging, and even skin disorders like acne and eczema.

Nano-formulations are increasingly being used. The applications in the skincare market extend from anti-aging serums to sunscreens, meaning the scope to treat and prevent skin conditions more effectively is wide. However, all these exciting possibilities come with a challenge of safety, regulation, and long-term effects from using nanotechnology in personal care products. The article continues to discuss the principles of nano-formulations, mechanism of action, and the latest developments in this field, which throws light on how nanotechnology is changing the future of skincare and providing solutions to age-old problems associated with the skin.

II. NANO-FORMULATIONS: PRINCIPLES AND ROLE IN SKIN CARE

Nano-formulations are the inclusion of nanotechnology in formulations for products, which aims at encapsulating, delivering, or enhancing the effectiveness of active components using nanoparticles in sizes mostly between 1 and 100 nanometers in all types of products, including skin care products. Materials behave differently under size conditions at the nanoscale than their counterparts at larger scales. The properties include enhanced surface area, improved solubility, and better chemical stability, making them well-suited for applications such as in skincare.

Active ingredients, such as antioxidants, vitamins, peptides, or moisturizers in nano-formulations, are typically encapsulated within nano-sized carriers such as liposomes, solid lipid nanoparticles, or polymeric nanoparticles. These carriers prevent degradation of the active ingredients, enhance absorption into the skin, and in some cases, permit targeted delivery to particular layers of the skin. This makes them better than regular formulations for a more effective treatment and a higher performance as they reach the deeper layers of the skin, where the treatment is needed the most.

In essence, nano-formulations provide a more efficient and controlled delivery for better product stability, less irritation, and generally better performance. Increasingly, they are being used in the skincare industry because they enhance the performance of products, particularly regarding aging, acne, pigmentation, and hydration. This means that such formulations could transform how active ingredients are applied and how skincare products perform.

Principles of Nano-Formulations:

Nano-formulations rely on the use of nanoparticles, which are particles that range within 1 to 100 nanometers in general. At this scale, materials reflect unique physical and chemical properties as well as those different from those measured on a bulk scale. Among such properties as high surface area, good solubility, and better stability, it is the nanoparticles that appear to be the best candidate for their use in formulations that have to do with skincare. The application of these nanoparticles in nano-formulations encapsulates the active ingredients. This allows control over their delivery and ensures the maintenance of stability in the formulation during application.

Some of the significant factors considered while designing nano-formulations are solubility in the active ingredient, barrier characteristics of the skin, and necessity for targeted release. Several nanocarrier systems, including liposomes, micelles, and solid lipid nanoparticles (SLNs), are used to incorporate and protect sensitive ingredients to ensure their delivery toward specific layers of the skin. These carriers can also minimize degradations that depend on environmental degradation, such as degradation caused by ultraviolet radiation or degradation after exposure to air. On the other hand, nanoformulations can activate a controlled mechanism of release which can extend action time of the active ingredients besides enhancing their therapeutical response.

Role of Nano-Formulations in Skin Care:

Nano-formulations play various roles in skin care- such as stabilizing ingredients and enhancing the penetration of these ingredients or even targeting specific skin layers by acting almost as if they were traditional formulations. One of the major reasons is that they may provide a greater penetration of active ingredients to deeper layers of the skin, which could not be accomplished by traditional formulations. For instance, active ingredients such as antioxidants, retinoids, and peptides are more efficiently transferred to the dermal layer, then it can act at its highest level, for example, wrinkles reduction or boosting the production of collagen.

Additionally, nano-formulations can solve more efficiently different types of skin issues. Nano-formulations can direct active ingredients just where they might be needed such that the problem is targeted, as in the cases of acne, hyperpigmentation, and dehydration. For example, nano-encapsulated sunscreens provide a better method for protecting skin against harmful rays from the ultraviolet spectrum. This is through better binding unto the skin itself. Similarly, anti-aging products are enhanced through the penetration of nano-particles to a deeper layer of the skin, thus providing greater and longer-lasting effects.

Overall, nano-formulations have transformed the skincare industry by providing delivery systems that could be more effective, enhancing the performance of the product, and enabling a range of benefits that could be brought to the skin. The further development of this technology will bring it closer to the ultimate goals of improving efficacy and precision in skincare applications for consumers.

III. MECHANISMS OF ACTION IN SKIN CARE

Nano-formulations are a very unique approach towards skin care through properties where the nanoparticles are supposed to enhance delivery, effectiveness, and stability of active ingredients. In the applications of nano-formulations, skin care involves action mechanisms that focus on how the tiny particles interact with layers of the skin and how they enhance absorption and provide targeted delivery. These are the primary mechanisms by which these nano-formulations work.

1. Enhanced Penetration and Absorption

The other major mechanism through which nano-formulations enhance skin care lies in enhanced penetration of the active ingredients in the skin. Since most ingredients are repelled by the stratum corneum, the outer layer of the skin, most ingredients fail to penetrate the skin well. Since these particles have a resulting high surface area due to being nano-sized, they penetrate past this barrier much more easily. They can penetrate the lipid layers of the skin and reach deeper areas such as dermis, hence exerting even more significant influence. For instance, hydrating agents, antioxidants or anti-aging ingredients encapsulated in nano-carriers can penetrate far beyond what a conventional formulation will allow, thus proving to be far more direct as well as permanent.

2. Control and Sustained Delivery

Nanoformulations allow controlled and sustained delivery over time. The nano-size carrier allows for the controlled release of active compounds in that it eliminates quick degradation or evaporation that is seen in the traditional ones. In this regard, slow and controlled release ensures there is a steady supply of the active ingredient throughout the day and night. For example, sunscreens using nano-formulations can provide long-lasting protection from UV rays, while moisturizers can ensure extended hydration through continuous release of moisturizing agents.

3. Targeted Delivery

Nano-formulations are highly efficient in delivering active ingredients to targeted areas of the skin, providing more precise treatments. The nanocarriers can be engineered to release ingredients in specific locations, such as areas of the skin affected by acne, pigmentation, or wrinkles. This level of accuracy makes possible better treatment for a localized concern within the skin; hence, applications that will need to be broad in use are often circumvented with non-specific effects as often as possible. Additionally, the nano-formulation can limit contact with healthy tissue by working to reach precise strata, meaning less possible interference with side reactions and irritation.

4. Nanoformulations increase stability and provide protective coverages on active agents.

Most skin care active ingredients are sensitive to light, heat, or oxygen, so they degrade in time and become less potent. Nano-formulations create a kind of protective wrapping that shields them from oxidation or UV damage. Compounds within nano-carriers get protected to

keep them stable till they are absorbed by the skin. This works well for such sensitive actives as vitamins C and E, retinoids, and peptides as they degrade according to environmental factors.

5. Low irritation and sensitivity

Formulations made of traditional compounds usually cause irritation, especially at active ingredient concentrations; this is because very few people can put up with certain levels of them. Nano formulations minimize side effects by effective and controlled delivery to the skin through well-controlled concentration and release of the active ingredients. Another way in which the encapsulation process minimizes direct contact with the skin includes the reduction in irritation. This way, nano-formulations may be used by sensitive skinned people or people who quickly react to chemicals.

6. Improvement of Skin Barrier

Some nanoformulations are designed to enhance the natural barrier function of the skin. This is achieved by allowing the nanoparticles to interact with lipids and proteins of the skin, which enhances the barrier function to retain moisture and protect from environmental stressors. This could help in conditions such as dry skin or compromised skin barriers, which are commonly found in diseases like eczema or psoriasis. Nano-formulations will also improve the healing and repair of the skin by promoting regeneration of skin cells and improving the delivery of healing agents.

All of these mechanisms of action in the skin with nano-formulations are based on enhanced penetration, controlled release, targeted delivery, improved stability, reduced irritation, and overall efficacy. These capabilities enable skincare products to achieve more precise, effective, and longer-lasting results, thus making nano-formulations an innovative solution to modern skincare challenges.

IV. TYPES OF NANO-FORMULATIONS IN SKIN CARE

Nano-formulations emerged as a backbone in a modern system of skincare. Formulations were conceived to deliver, stabilize, and enhance the activity of the active ingredients in the system. There are different kinds of nano-formulations that are applied to skin care products to suit various skin types and achieve the maximum benefits of ingredients. The major types of nano-formulations in skin care are given below:

1. Liposomes

Liposomes are spherical vesicles with active ingredients and are composed of a phospholipid bilayer. They are one of the most used types of nano-formulations in skin care. Liposomes can carry both hydrophilic and hydrophobic ingredients into the skin efficiently. The lipid bilayer resembles the natural cell membrane of the skin, which is why liposomes are especially good at penetrating the skin barrier. They also protect sensitive ingredients, such as

vitamins and antioxidants, from degradation and ensure stability. They are extensively used in anti-aging creams, moisturizers, and serums.

Advantages:

- It helps improve the penetration and delivery of the active ingredient.
- It protects fragile molecules from degradation.
- They can be used with hydrophilic as well as lipophilic drugs.

2. Niosomes

Niosomes are another type of liposome, but it consists of non-ionic surfactants. Liposomes consist of phospholipids. In niosomes, the non-ionic surfactants self-assemble into bilayer vesicles that trap the active ingredient. Niosomes are as advantageous as liposomes: delivery and stability improved, yet may be more cost-effective and more flexible in formulation. Formulations with higher percentages of surfactants also are more stable in niosomes. Niosomes are broadly used for encapsulating vitamins, peptides, herbal extracts, etc., in the formulation of skin care products.

Advantages

- Cost-effective and stable in various formulations.
- Capable of encapsulating both hydrophilic and hydrophobic compounds.
- Provides controlled and sustained release of ingredients.

3. Nanostructured Lipid Carriers (NLC)

Nanostructured Lipid Carriers (NLC) are solid lipid nanoparticles consisting of a blend of solid and liquid lipids. The blend enhances the stability, loading capacity, and release properties of the active ingredients. NLCs are prepared to enhance the delivery of poorly soluble ingredients such as some antioxidants, vitamins, and UV filters into the skin. NLCs allow better penetration of the skin with controlled release, keeping active ingredients effective for a longer time.

Advantages:

- High drug loading for active ingredients
- Better stability as compared to other conventional formulations.

- Controlled and sustained release is good for prolonged action. 4. Solid Lipid Nanoparticles (SLN)

SLNs are a type of lipid-based nano-formulation in which the active ingredient is encapsulated with solid lipids. SLNs are stable and have a controlled release profile, which is effective for delivering active compounds over time. They are particularly useful for sensitive ingredients such as retinoids or essential fatty acids that can easily be degraded in traditional formulations. SLNs can also increase the moisturizing effect of the skin and are mainly used in anti-aging, moisturizing, and UV protection products.

Advantages:

- It protects sensitive ingredients from oxidation and degradation.
- It delivers sustained-release prolonged effectiveness.
- Improves hydration of the skin and overall integrity of the skin barrier.

5. Polymeric Nanoparticles

Polymeric nanoparticles are synthetic or natural polymers that are applied for encapsulation of active ingredients in various skin care formulations. Such nanoparticles may also be designed to result in the controlled release of the active ingredients, target specific layers of the skin, and improve bioavailability of active compounds involved. Especially useful for the delivery of water-insoluble or poorly bioavailable ingredients such as antioxidants, peptides and anti-inflammatory agents, nanoparticles can be programmed to be responsive to particular environmental stimuli, such as pH and temperature.

Advantages:

- Versatile and customizable for targeted delivery.
- Applicable for a wide variety of active ingredients
- Can be designed to deliver ingredients under the impetus of specific triggers.

6. Micelles

Micelles are spherically shaped assemblies formed by amphiphilic molecules that self-assemble in aqueous solutions. Most common practice is to formulate a water-based skin care product with micelles as it easily solubilizes hydrophobic ingredients, making them water-soluble and dispersible in water. Cleansers are usually based on a micellar system since it is quite efficient in cleaning off dirt, oil, and makeup without breaking down the skin's natural barrier. These feel soft on the skin and thus ideal for sensitive types of skin.

Advantages

- They are mild and effective cleansing agents.
- These can dissolve hydrophobic ingredients in aqueous-based systems.
- They are ideal for sensitive skins and also for makeup removal.

7. Dendrimers

Dendrimers are highly branched tree-like structures, which are composed of synthetic polymers. They can be engineered to possess multiple functional groups on their surface. They can be designed to encapsulate several active ingredients or to target specific receptors on the skin. Dendrimers are great for delivering highly concentrated active ingredients in a targeted and controlled manner. They can also be used in formulations targeting particular issues such as acne or wrinkles, where efficacy of the ingredients, such as retinoids or antibiotics, is increased.

Advantages

- It can be designed precisely for size and structure, having targeted delivery.
- High loading of active ingredients is possible.
- It can be engineered to serve particular therapeutic uses-anti-aging, for example, or treating acne.

Different types of nano-formulations offer different types of advantages in skincare applications such as liposomes, niosomes, NLCs, SLNs, polymeric nanoparticles, micelles, and dendrimers. These generally enhance the penetration, control the release, and stabilize the active ingredients for better treatment of a wide range of skin-related problems. Advanced technologies used in these formulations can provide the best possible skincare products to deliver effective, long-lasting, and personalized solutions to the consumer.

V. CURRENT APPLICATIONS IN SKIN CARE

Nanotech completely altered the skincare world, particularly optimizing the delivery as well as activity of active agents. Nowadays, nano-formulation is applied throughout various classes of skincare treatments for most of the skincare issues, including aging and wrinkles, comedonal as well as pigmentation problems, hydration and photoprotection of the skin. Here are some of the principal applications that currently exist with nanotechnology for cosmetic treatments:

1. Aging and Wrinkles

One of the most significant applications of nano-formulations in skincare is for anti-aging products. Anti-aging serums, creams, and masks use different types of nano-encapsulated retinoids, peptides, and antioxidants, for instance. This is because nanoparticles can penetrate

deeper into the skin than other particles, especially deeper to the dermal layers where collagen and elastin are found. This allows the active ingredients to induce collagen synthesis, remove fine lines, and improve the elasticity of the skin. Additionally, nano-formulations allow for the controlled release of active ingredients, which translates to long-term anti-aging effects.

Sample Products:

- Serums and creams containing retinol with nano-particles to penetrate deeper into the skin.
- Anti-aging products rich in peptides that focus on wrinkles and sagging.

2. Sun Protection and Sunscreens

Nano-formulations are the cornerstone of modern sunscreen technology. The older traditional sunscreen formulations rely more heavily on chemical filters or larger physical blockers. Nano-formulated sunscreens, however, are made up of nanoparticles of zinc oxide and/or titanium dioxide to form the very effective and more transparent UV protection. Nano-sized particles of these minerals allow for higher coverage and stability in the form of better protection for the user against the dangers of harmful UVA and UVB radiation. Also, nano-formulations would promote a non-greasy feel that is lightweight, more suitable for casual daily wear.

Example Products:

- Nano-sized titanium dioxide or zinc oxide sunscreens that give broad-spectrum protection without a white residue.
- Water-resistant sunscreens formulated with nano-particles for extended protection.

3. Acne Treatment

Nano-formulations are very effective in acne treatment products. These include encapsulation in nano-particles for improving the stability and targeted delivery of benzoyl peroxide, salicylic acid, and clindamycin antibiotics. The nano-carriers are much smaller in size; therefore, active ingredients can penetrate deeper into the skin and target the sebaceous glands where acne is developed. Furthermore, nano-formulations minimize irritation often caused by treatments for acne as the ingredients are delivered more slowly and precisely.

Example Products:

- Nano-encapsulated acne creams or gels delivering controlled release to impacted pores

- Topical nano-encapsulated antibiotics: control bacterial attack minus excessive drying or irritation of the skin surface

4. Hydration and Moisturizer

Moisturizers contain very high uses of nano-formulation, including a hydration-optimizing barrier layer. The solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) can encapsulate the moisturizing agents such as ceramides, fatty acids, and hyaluronic acid efficiently and deliver them to the deeper layers of the skin. It is proven that these nano-carriers can better penetrate the skin barrier compared with traditional formulations and show better moisture retention and hydration of the skin. Nano-formulations also fortify the natural barrier function of the skin in terms of maintaining moisture and environmental protection.

Products,

- Hydrating serums or creams containing hyaluronic acid nano-encapsulated for providing deep moisture supply and retention.
- Moisturizing creams with nano-formulated ceramides that mend the protective barrier of the skin.

5. Skin Brightening and Hyperpigmentation

Nano-formulations are also used crucially in the formulation of products with hyperpigmentation treatments of skin brightening. Such an active ingredient encapsulated within a nano-particle includes vitamin C, niacinamide, or hydroquinone for enhanced permeation and diffusion into the system. The result of such action will ensure active ingredient delivery straight to the point of pigmentation for fast actions and improved effectiveness. Besides this, the nano-encapsulation also safeguards against oxidation that results in degradative activity against the active ingredients and helps stabilize the potency during long storage time.

Examples include;

- Nano-encapsulated ascorbic acid serums are used for vitamin C better for brightening and antioxidant protection
- Brightening creams containing nano-particles of niacinamide or hydroquinone, for targeting skin tones for unevenness and dark spots.

6. Wound healing and Skin Regeneration

Nano-formulations have been employed in products intended to enhance the healing and regeneration of skin tissues, particularly of damaged or impaired skin. Growth factors, peptides, and other healing agents could be easily introduced into the target areas with these nano-sized particles. These induce collagen synthesis and accelerate regeneration as well as

may decrease inflammation at the site on the skin. Nano-formulations are also part of treatments given for acne marks, burns, and postoperative wounds, essentially because they are effective in repairing and regenerating tissues in the skin.

Example Products:

- Wound-healing cream or gel products containing nano-encapsulated peptides or growth factors.
- Scar treatment product using nano-particles of enhancing collagen synthesis and skin rejuvenation.

7. Eye Care and Sensitive Skin

Nano-formulations would be of great use to very sensitive areas especially eyes or sensitive skin types where active ingredients may not be tolerated at a particular concentration. Nano-sized particles could be used for eye creams and gels. These can specifically target puffiness, dark circles, and fine lines. When it comes to sensitive skin which easily reddens, irritates, or breaks out in allergies, nano-formulated products come as a gentle alternative. Control release and the precise delivery of ingredients make them both effective and gentle on those sensitive skin areas.

Example Products:

- Nano-encapsulated caffeine or peptides eye creams reduce puffiness and dark circles.
- Gentle moisturizers based on nano-carriers that avoid irritation to sensitive skin.

Nano-formulations are becoming popular in almost all categories of skincare products, promising more efficacy and targeted solutions to deal with various issues in the skin. Applications range from anti-aging and acne treatments to sun protection, hydration, and wound healing, among others, and are continuously on the rise with the advancement of technology. Nano-formulations improve the stability, penetration, and controlled release of active ingredients in skincare products, thereby making these products more effective, personalized, and accessible to consumers worldwide.

VI. CONCLUSION

Nano-formulations are the new integration in skincare, providing improved efficacy, precision, and stability. Nanotechnology will help formulations deliver the active ingredient much better to reach deep into the layers of the skin for long periods with precise, targeted action. With nano-encapsulated systems, sensitive compounds' stability is improved, controlled release guaranteed, and skin irritation from these inhibited and ideal for most types and concerns. Applications of nano-formulations range extensively and diversify from anti-aging and acne treatments to hydration, skin brightening, and sun protection. Nano-formulations offer solutions which cannot be attained with traditional formulations, like

improved bioavailability and increased penetration across the barrier of the skin. With research moving forward further, nano-formulations will soon give the consumers a chance of better, more customized treatments of their skin problems. Though the promises are enormous about nano-formulations, their safety and long-term effects and standards continue to be the key for further implementation in practices. Future skincare would definitely dwell further on this line of thinking as nanotechnologies advance in cosmetic sciences and so would next generation skincare as people become further educated on nano technology in cosmetic formulation.

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