WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
Coden USA: WJPRAP Impact Factor 8.63
Volume 15, Issue 4, 855-874. Research Article ISSN 2277–7105

REVIEW ON MICROSPONGE-BASED TOPICAL DELIVERY: A NOVEL APPROACH FOR IMPROVED ANTI-INFLAMMATORY THERAPY

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Article Received on 14 Jan. 2026,
Article Revised on 04 Feb. 2026,
Article Published on 15 Feb. 2026,

https://doi.org/10.5281/zenodo.18661088

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How to cite this Article: Krishna K. R.[1], Shashank H. S.[2]*, Parthiban S.[3] (2026). Review on Microsponge-Based Topical Delivery: A Novel Approach for Improved Anti-Inflammatory Therapy. World Journal of Pharmaceutical Research, 15(4), 855–874.

ABSTRACT

The microsponge delivery system is a novel polymer-based approach developed to improve the performance of topical drug delivery. It comprises highly cross-linked, porous microspheres that can encapsulate active substances and release them in a controlled manner over an extended duration after application to the skin. This controlled release behaviour provides multiple advantages, such as prolonged therapeutic activity, reduced incidence of skin irritation, better patient compliance, and enhanced thermal, physical, and chemical stability of the formulation. Microsponges are prepared using various manufacturing techniques, including liquid–liquid suspension polymerization and emulsion-based processes. These methods generate a porous internal structure that enables regulated diffusion of the active ingredients. Owing to their distinctive characteristics, microsponges are widely incorporated into dermatological and cosmetic dosage forms such as creams, gels, powders, and lotions. Furthermore, microsponge systems are capable of encapsulating a broad range of pharmaceutical and cosmetic agents, including anti-inflammatory drugs, skin-brightening agents, sunscreens, and anti-aging compounds. A major advantage of this delivery system is its ability to enhance drug penetration into the skin while minimizing irritation, which makes it particularly suitable for formulations intended for sensitive skin. The sustained-release nature of microsponges also ensures prolonged therapeutic efficacy, thereby reducing the frequency of application. This review highlights microsponge technology with emphasis on

its preparation methods, advantages, benefits, characteristics, evaluation parameters, and drug release mechanisms in topical drug delivery systems.

KEYWORDS: Microsponge, Microsphere, Topical delivery, Skin penetration, Quasi emulsion solvent diffusion.

INTRODUCTION

Microsponges are porous, polymer-based microspheres primarily designed for topical application over prolonged durations. They are engineered to enhance formulation stability, reduce adverse effects, and modify drug release characteristics, thereby enabling efficient delivery of pharmaceutically active ingredients at minimal effective doses. The Microsponge Drug Delivery System (MDDS) is a patented technology composed of highly cross-linked, porous polymeric microspheres with particle sizes typically ranging from 10 to 25 µm. These microspheres possess an extensive internal porous network that allows the encapsulation of a wide range of active substances, including prescription drugs, cosmetic ingredients, over-the-counter skincare products, and sunscreens. The entrapped actives are released gradually onto the skin in a controlled manner or in response to specific external stimuli, ensuring sustained and targeted topical delivery.[1]

Microsponges are polymer-based drug delivery systems consisting of highly porous micro spherical structures. These minute sponge-like spherical particles possess an extensive internal porous network and are capable of enhancing formulation stability, minimizing adverse effects, and favourably regulating drug release behaviour. Owing to their numerous advantageous properties, microsponge technology serves as a versatile platform for drug delivery. Microsponge systems are composed of microscopic polymeric microspheres that can encapsulate or adsorb a wide range of active substances. These microspheres can be readily incorporated into various dosage forms, including gels, creams, liquids, and powders. The microsponge delivery system enhances the therapeutic efficacy of topically administered agents by improving safety, prolonging product stability, and offering better aesthetic acceptability in an efficient and controlled manner.[2,3]

Topical drug administration is a targeted method of drug delivery in which medicaments are applied directly onto the skin or other body surfaces to achieve superficial, localized, or systemic therapeutic effects. Among topical routes, the skin is the most commonly used and easily accessible, and the success of treatment mainly depends on selecting an appropriate

formulation base and an effective delivery system. Topical formulations usually contain active substances incorporated into suitable vehicles, which may also provide moisturizing, soothing, or protective benefits. Recent developments in topical drug delivery, such as advanced carriers, permeation enhancers, and non-invasive techniques, have enhanced drug effectiveness, improved patient acceptability, and resulted in better clinical outcomes for various dermatological conditions.[4]

Topical drug delivery systems are designed for the direct application of formulations containing active pharmaceutical ingredients onto the skin to produce a localized therapeutic action. These systems provide benefits such as targeted delivery at the site of application, prevention of gastrointestinal disturbances, and bypassing hepatic first-pass metabolism, which enhances bioavailability and supports prolonged drug release. In topical administration, the drug is released from the dosage form and penetrates through the skin layers to reach the required site of effect. Percutaneous absorption may be improved by increasing the rate of drug release, which depends on the physicochemical characteristics of the drug as well as the carrier system. Moreover, topical delivery helps minimize systemic adverse effects and increases patient adherence because of its convenient and non-invasive use. Therefore, it is widely utilized for treating various skin diseases and other localized disorders.[5]

ANATOMY OF SKIN

The skin is the largest organ of the body, accounting for about 15% of the total adult body weight. It performs many vital functions, including protection against external physical, chemical, and biologic assailants, as well as prevention of excess water loss from the body and a role in thermoregulation. The skin is continuous, with the mucous membranes lining the body's surface.[6]

The skin is composed of three layers

1. Epidermis,
2. Dermis,
3. Hypodermis

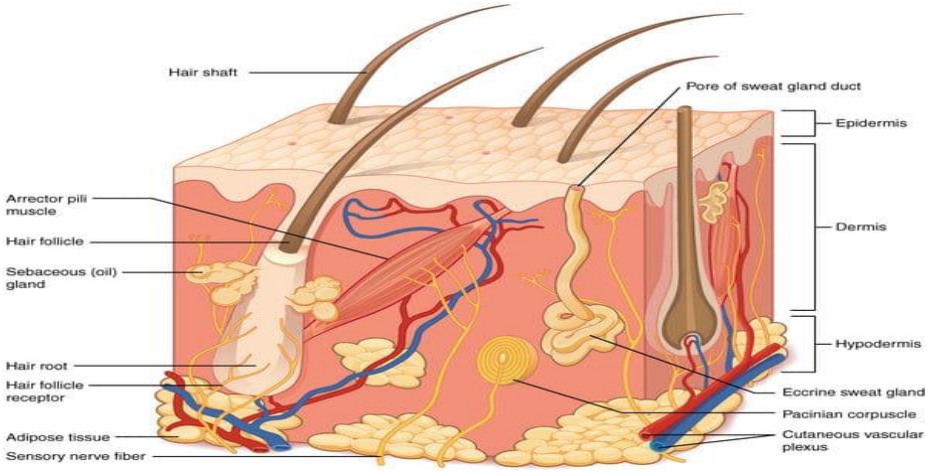

Fig.no 01: Structure of Skin.

Epidermis

The epidermis is the outermost layer of the skin, formed mainly by stratified squamous keratinized epithelium. It acts as the primary protective barrier of the body against microorganisms, chemicals, dehydration, and UV radiation. The major cells present in the epidermis are keratinocytes (main structural cells), along with melanocytes (pigment production), Langerhans cells (immune defense), and Merkel cells (touch sensation).The epidermis is arranged into distinct layers: stratum basale, stratum spinosum, stratum granulosum, stratum lucidum (only in thick skin), and stratum corneum. The stratum corneum is the most important barrier layer, composed of dead, flattened corneocytes embedded in lipids, helping prevent water loss and entry of harmful agents. Continuous cell renewal occurs as basal cells divide and migrate upwards, undergoing keratinization, which maintains skin integrity and supports wound healing.[7]

Dermis

The dermis is the middle layer of skin, located below the epidermis and above the subcutaneous tissue. It provides strength, elasticity, and structural support to the skin due to the presence of collagen and elastin fibers. The dermis is mainly composed of connective tissue and contains important structures such as blood vessels, lymph vessels, nerves, hair follicles, sweat glands, and sebaceous glands. It is divided into two layers: the papillary dermis (superficial, loose connective tissue) and the reticular dermis (deeper, dense connective tissue). The dermis plays a major role in nutrition of the epidermis, thermoregulation, sensation, and wound healing by supporting cellular repair and immune responses.[8]

Hypo-dermis

The hypodermis mainly consists of loose connective tissue which depending on site forms gliding layers or large pockets of adipose tissue that insulates and protects the skin.[9]

Advantages of topical drug delivery system

- Hepatic first pass metabolism, as well as salivary and intestinal metabolism, are by passed.
- The user-friendly nature of these systems enables easy self-administration by patients.
- In case of an emergency, removing the patch at any point of time during therapy can instantly stop drug input.
- Since the composition of skin structurally and biologically is the same in almost all humans, there is minimal inter and intra patient variation.
- Drugs showing gastrointestinal irritation and absorption can be suitably administered through skin.
- Continuous, non-invasive infusion can be achieved for drugs with short biological half-life which would otherwise require frequent dosing.
- Due to reduced frequency of dosing, there is better patient compliance.
- Therapeutic failures resulting from dosing inconsistencies associated with conventional dosages forms can be minimized.[10]

Disadvantage of topical drug delivery system

- Potential for skin burns if electrodes are not applied correctly
- Challenges in maintaining the stability of the therapeutic agent within the formulation vehicle
- Complicated drug release mechanism
- May require an extended duration for administration
- Mild sensations such as tingling, irritation, or burning may occur
- An intact stratum corneum is necessary for efficient drug permeation
- Not suitable for application over large surface areas
- High voltage may disrupt or damage the loaded drug
- Risk of cellular injury
- Limited targeting specificity.[11]

Types of topical drug delivery systems

1. Gels/Creams

It is topically administered for the management of skin disorders such as seborrheic dermatitis, rosacea, and acne vulgaris. Various approaches have been employed to enhance drug penetration through the skin by using suitable vehicles or penetration enhancers, including propylene glycol, fatty acids, and alcohols, to effectively relieve the aforementioned symptoms.

2. Nano-colloidal carrier

Nanostructured lipid carriers (NLCs) represent the second generation of nanoscale lipid-based delivery systems designed to transport both hydrophilic and lipophilic drugs. Incorporation of a liquid lipid into the solid lipid matrix enhances drug-loading capacity and minimizes drug expulsion, a limitation commonly observed with solid lipid nanoparticles (SLNs). Due to their stability, biocompatibility, and biodegradability, NLCs are well suited for sustained or controlled topical drug delivery for both local and systemic therapeutic applications.

3. Microneedles

Microneedles are two- or three-dimensional arrays of micro-projections, typically less than 100 µm in length, that enhance drug permeation across the stratum corneum by creating microscopic channels in the skin. This minimally invasive approach integrates the advantages of transdermal patches and hypodermic injections to deliver therapeutic agents such as proteins, peptides/polypeptides, and vaccines-into the viable epidermal layer of the skin. Due to their shallow penetration depth and lack of nerve stimulation, microneedles provide a painless mode of drug administration.

4. Hydrogels/modified hydrogels

Hydrogels are three-dimensional networks of hydrophilic polymer chains capable of retaining large quantities of water while preserving a gel-like consistency. They are extensively utilized in pharmaceutical formulations, cosmetic products, wound management, contact lenses, and various biomedical applications. Thermo-sensitive hydrogels represent an advanced category of formulations that undergo physical phase transitions in response to external stimuli. These colloidal, hydrophilic polymer systems derived from natural or synthetic sources-exhibit a reversible transformation from a sol state to a gel state upon changes in temperature.

5. Rapid dissolving tablets

Rapid-dissolving tablets (RDTs), also known as orally disintegrating tablets (ODTs) or fast-melt tablets, are formulated to disintegrate rapidly in the oral cavity without the need for water. These dosage forms typically contain bio adhesive polymers such as hydroxypropyl cellulose, low-substituted hydroxyethyl cellulose, polyvinylpyrrolidone (PVP), polyvinyl alcohol (PVA), polyethylene oxide (PEO), chitosan, and carrageenan, along with sugar alcohols or saccharides including glycerol, arabitol, sorbitol, maltitol, and xylitol. They also incorporate active pharmaceutical ingredients (APIs) such as antimicrobial, antiviral, anti-migraine, anti-Parkinson, contraceptive, and hormonal agents.

6. Pressure sensitive adhesive

Pressure-sensitive adhesive systems are simple, self-applicable, stable, and reversible drug delivery platforms designed to provide sustained medication release over prolonged periods following a single application. When mild pressure is applied, these formulations readily adhere to biological surfaces and can be easily removed upon completion of therapy or in the event of an adverse reaction.

7. Soft gelatine capsules.

Soft gelatine capsules are unit solid dosage forms consisting of a hermetically sealed gelatine shell enclosing liquid or semi-solid pharmaceutical preparations. They are widely employed in drug delivery to enhance bioavailability and therapeutic performance owing to their stability, biocompatibility, and biodegradable properties.

8. Suspensions

A suspension is a liquid dosage form in which finely divided solid particles are uniformly dispersed within a liquid vehicle. Suspending agents are incorporated to maintain homogeneity, while wetting agents facilitate the dispersion of poorly water-soluble or hydrophobic drugs. Flocculating agents are used to minimize caking, and preservatives are added to prevent microbial contamination. Appropriate viscosity adjustment ensures ease of pouring while reducing the rate of sedimentation. Suspensions are commonly employed in oral, topical, parenteral, and ophthalmic preparations to enhance patient acceptability and compliance.

9. Colloidal carriers

Lipophilic drugs can be administered topically to the posterior segment of the eye using microemulsion-based ophthalmic formulations. Microemulsions are optically transparent and thermodynamically stable systems composed of nanosized dispersed droplets uniformly distributed within a continuous phase. Owing to their intrinsic properties, unique structural organization, and sustained drug-release behaviour, microemulsions represent an attractive platform for ocular drug delivery.

10. Contact lens

A translucent, biomimetic contact lens–based carrier has been developed to enhance drug-loading capacity and provide prolonged, uniform drug release. The soft contact lens is fabricated from a responsive polymeric hydrogel composed of silicon, carbon, and organic-based polymer chains.[12]

ROUTE OF PENETRATION

As illustrated in the figure, drug molecules may permeate the skin either through shunt pathways-primarily via widely distributed hair follicles and eccrine sweat glands-or directly across the epidermal layers during percutaneous absorption. In the initial transient phase of diffusion, drugs can enter the skin through sweat ducts or hair follicles, followed by uptake into the sebaceous glands and follicular epithelium. Once steady-state conditions are established, diffusion across the intact stratum corneum becomes the dominant route for transdermal drug permeation.[13]

MICROSPONGES DRUG DELIVERY SYSTEM

Microsponges are microscopic, spherical carrier systems made of highly porous polymeric microspheres with a sponge-like structure. These small particles are capable of entrapping, adsorbing, or retaining a wide variety of substances within their pores. After loading, they can be incorporated into finished formulations such as gels, creams, lotions, liquids, or powders. Microsponge technology is considered a flexible and advanced drug delivery approach due to its multiple benefits. It improves the therapeutic performance of topically applied drugs by enabling controlled and prolonged release. This system also enhances patient safety by reducing irritation and minimizing unwanted side effects. In addition, micro sponges contribute to better formulation stability by protecting the active ingredient. They also improve the aesthetic and cosmetic acceptability of the final product. A major challenge in pharmaceutical development is to regulate the drug release rate at the target site in the body.

Therefore, several reliable systems have been developed that utilize the skin as a route for systemic drug delivery.[14]

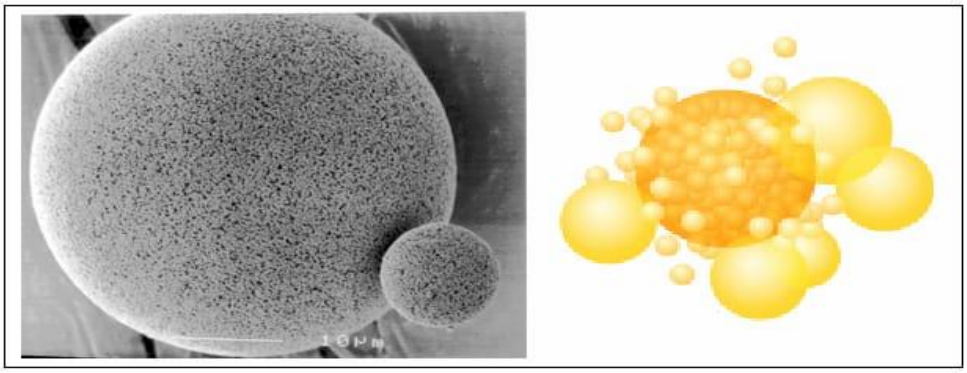

Fig. no 02: Microscopic structure of microsponge.

BENEFITS OF MICROSPONGE DRUG DELIVERY SYSTEM

- Enhanced overall product efficacy.
- Prolonged and controlled drug release.
- Decreased skin irritation, leading to better patient adherence.
- Improved aesthetic appeal of the formulation.
- Superior oil-absorbing capacity, capable of retaining up to six times its own weight without causing dryness.
- Greater flexibility in formulation design.
- Increased thermal, physical, and chemical stability.
- Capability to develop innovative and diverse dosage forms.
- Microsponge systems are safe and well tolerated, being non-irritant, non-mutagenic, non-allergenic, and non-toxic.[15,16]

CHARACTERISTICS OF MICROSPONGES

- Stable in pH range of 1 to 11.
- Maintains stability at temperatures as high as 130 °C.
- Exhibits compatibility with a wide range of excipients and active pharmaceutical ingredients.
- Possesses self-sterilizing properties, as microorganisms are unable to penetrate pores with an average size of approximately 0.25 µm.
- Capable of carrying a high drug load, typically ranging from 50% to 60%.
- Economical in nature and demonstrates good flow characteristics.[17]

ADVANTAGES OF MICROSPONGE

1. The integration of immiscible material is made possible by the microsponge delivery method
2. It decreased irritant formulation
3. It exhibits continuous action for up to 12 hours and prolonged drug release
4. Non-toxic, non-mutagenic, non-irritating, non-allergic microsponges
5. It increases the effectiveness of treatment
6. Physical, chemical and thermal stability are also improved
7. It improves control of condition
8. It improves processing of materials Eg: liquid can be converted to powders
9. Microsponge improves bio availability of same drug.[18,19]

APPLICATION OF MICROSPONGES

❖ Topical application

A topical drug delivery system refers to a formulation designed to transport a specific therapeutic agent into the skin. The movement of topical drugs across the skin's protective barrier presents a significant challenge. Topical delivery systems are broadly classified into two categories: external and internal topical preparations.

❖ External topicals

External topical preparations are applied directly to the surface of the skin, where the affected area is covered using methods such as spraying, spreading, or similar application techniques.

❖ Internal topicals

Internal topical preparations are those administered to mucous membranes, including the anorectal region, vaginal tissues, or the oral cavity. These formulations are primarily intended to produce localized therapeutic effects at the site of application by facilitating drug penetration into the underlying layers of the skin or mucosa. Although incidental systemic absorption may occur, it is generally minimal and remains below therapeutic levels.[20]

RELEASE MECHANISM OF MICROSPONGE

- The drug release from a microsponge delivery system occurs through multiple mechanisms.
- **Diffusion:** Involves the migration of drug molecules through the porous channels of the microsponge driven by a concentration gradient.

- **Erosion or degradation:** The polymeric matrix gradually liberates the entrapped drug as the structure breaks down over time.
- **Swelling:** Takes place when the microsponge absorbs surrounding fluids, leading to matrix expansion and subsequent drug release.
- **Pulsatile release:** The drug is discharged intermittently in distinct bursts followed by periods of controlled delivery.
- **Controlled release:** Refers to the sustained and prolonged liberation of the drug, governed by the unique architecture of the microsponge system.[21,22]

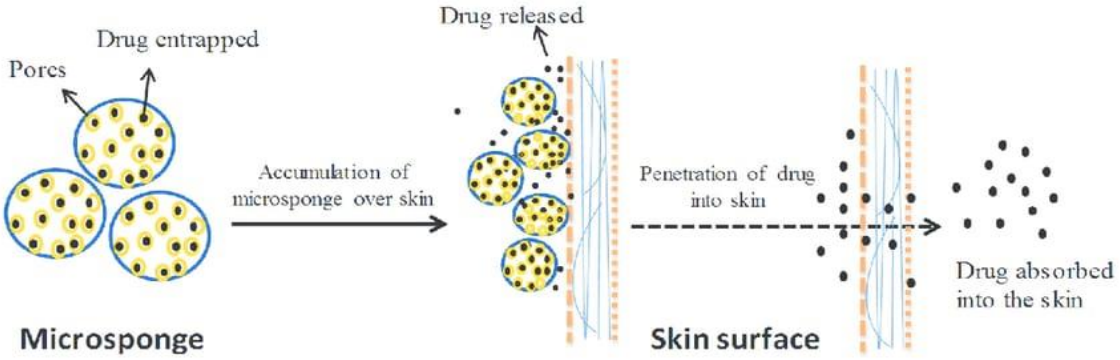

Fig.no 03: Representation of release mechanism of microsponge.

METHOD OF PREPARATION OF MICROSPONGE DRUG DELIVERY SYSTEM

In addition to the composition of the microsponge, the overall performance of the delivery system is largely influenced by the method used for its preparation. Nevertheless, the number of available microsponge fabrication techniques is limited due to their technical complexity and high cost. Drug incorporation and release can be accomplished through two main strategies: the one-step or two-step liquid–liquid polymerization method and the quasi-emulsion solvent diffusion technique. The selection of either method primarily depends on the physicochemical properties of the drug intended for encapsulation. For instance, non-polar and chemically inert drugs can act as pyrogens, leading to the formation of a porous structure, as shown in the figure. Pyrogen drugs that neither inhibit nor promote polymerization and remain stable in the presence of free radicals can be successfully encapsulated using the one-step polymerization method.[23,24]

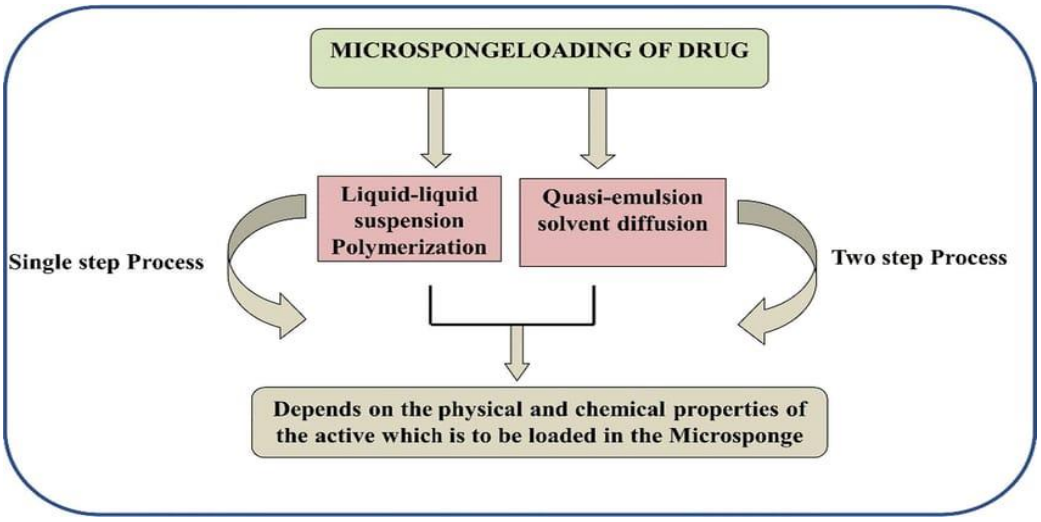

Fig.no 04: Method of preparation.

Liquid-liquid suspension polymerization

Porous microspheres are commonly produced using the suspension polymerization technique in liquid–liquid systems. In this approach, immiscible monomers are initially dissolved together with the active pharmaceutical ingredient in an appropriate solvent monomer. This organic phase is then dispersed into an aqueous phase containing additives such as surfactants and suspending agents, which promote the formation and stabilization of the suspension. Polymerization is subsequently initiated by elevating the temperature, exposing the system to irradiation, or introducing a suitable catalyst. As the reaction proceeds, a reservoir-type system with a spherical morphology is formed. Upon completion of polymerization, the solvent is removed, resulting in porous, spherical microspheres known as microsponges. The sequential steps involved in microsponge preparation are summarized below.

Step 1: Selection of monomer as well as combination of monomers.

Step 2: Formation of chain monomers as polymerization starts.

Step 3: Formations of ladders as a result of cross-linking between chain monomers.

Step 4: Folding of monomer ladder to form spherical particles.

Step 5: Agglomeration of microspheres leads to the production of bunches of microspheres.

Step 6: Binding of bunches to produce microsponges.[25]

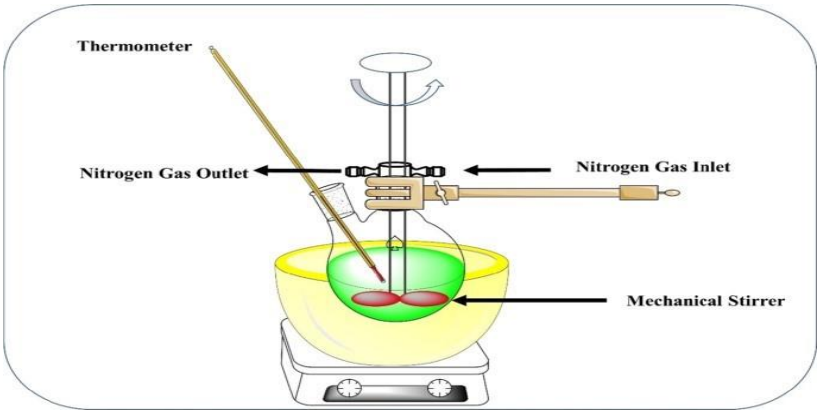

Fig. no 05: Representation of liquid- liquid suspension polymerization method.

Quasi-Emulsion solvent diffusion method

Porous microspheres, commonly referred to as microsponges, were also prepared using a quasi-emulsion solvent diffusion method, which involves a two-step process. In this technique, the internal phase consisted of a polymer dissolved in ethyl alcohol. The drug was gradually incorporated into the polymeric solution and completely solubilized using ultrasonication at 35 °C, followed by the addition of a plasticizer to enhance flexibility. This internal phase was then slowly introduced into the external aqueous phase containing distilled water and polyvinyl alcohol, under continuous stirring for two hours. After formation, the microsponges were separated by filtration, thoroughly washed, and subsequently dried in a hot-air oven at 40 °C for 12 hours.[26]

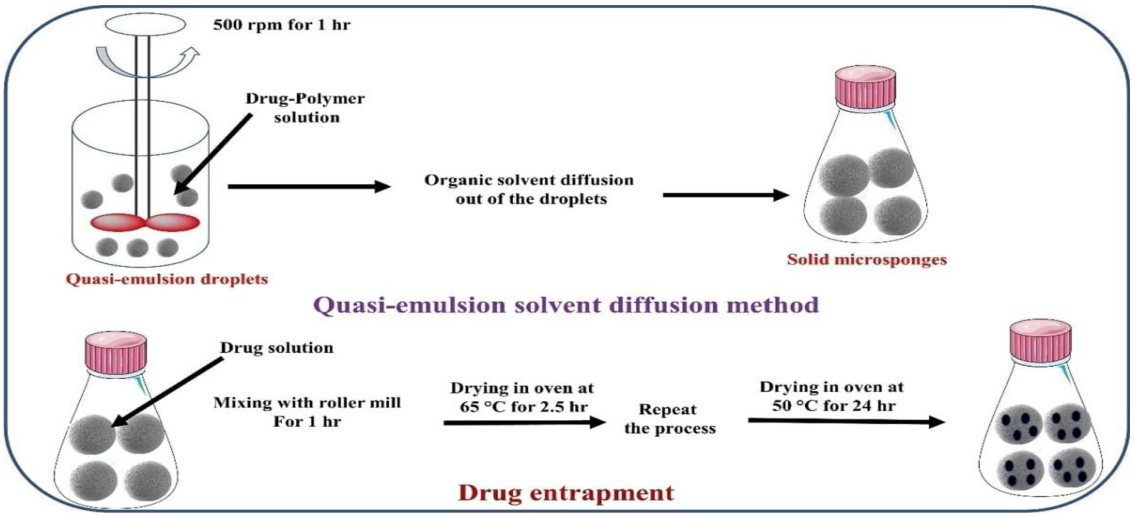

Fig. no 06: Representation of Quasi-emulsion solvent diffusion method.

EVALUATION PARAMETERS

1. Production yield

Production yield of microsponges was determined by formula mentioned below.[27]

Production yield = practical mass of microsponge/Theoretical mass X 100.

2. Morphology and Surface topography of microsponges

A thin layer of gold–palladium may be deposited onto the prepared microsponges at room temperature under an argon atmosphere. The surface characteristics of the microsponges can then be analysed using scanning electron microscopy (SEM). In addition, SEM can be employed to visualize the internal ultrastructure of fractured microsponge particles.[28]

3. Determination of loading efficiency

The following formula can be used to determine the microsponges loading efficiency.[29]

Loading efficiency = Actual Drug Content in Microsponge/Theoretical Drug Content X 100

4. Differential scanning calorimetry (DSC)

The thermal behaviour of the DDEA microsponges formulation was recorded using a differential scanning calorimeter fitted with an intercooler. Indium was used as the reference material to calibrate the temperature and enthalpy scales of the instrument. The microsponge samples were sealed in aluminium pans and subjected to heating from 10 to 200 °C at a constant heating rate of 10 °C per minute. Throughout the analysis, an inert environment was ensured by continuously purging nitrogen gas at a flow rate of 10 mL per minute.[30]

5. Particle size determination

Particle size analysis of loaded and unloaded microsponges can be performed by laser light diffractometry or any other suitable method. The values can be expressed for all formulations, size range. Cumulative percentage drug release from microsponges of different particle size will be plotted against time to study effect of particle size on drug release. Particles larger than 30 µm can impart gritty feeling and hence particles of sizes between 10 and 25 µm are preferred to use in final topical formulation.[31]

6. Scanning electron microscope study

The prepared microsponges may be sputter-coated with gold–palladium at room temperature under an argon atmosphere to facilitate the evaluation of surface features and morphological characteristics. The surface morphology of the microsponges can then be analysed using

scanning electron microscopy (SEM). Additionally, SEM may be employed to observe the internal ultrastructure of a fractured microsponge particle.[32]

7. Dissolution studies

Dissolution release rate of microsponges can be studied by use of dissolution apparatus with a modified basket consisted of 5µm stainless steel mesh. The dissolution medium is selected while considering solubility of actives to ensure sink conditions. At various intervals the samples from the dissolution medium was analysed by suitable analytical methods.[33]

8. Drug release kinetics

The amount of drug released vs time was used to certain the drug release mechanism and examine the variations in release profiles between microsponges. The following mathematical models were used to analyse the release data.[34]

$$Q = k_1 t^n \textbf{ OR } \log Q = \log k_1 + n \log t$$

9. Determination of true density

The true density of micro particles is measured using an ultra- pycnometer under helium gas and is calculated from a mean of repeated determinations.[35]

10. Stability study

Stability studies are conducted to confirm that the active pharmaceutical ingredient in a dosage form maintains its efficacy, safety, and quality throughout the storage period. The microsponge gel formulations were kept in tightly closed, amber-coloured glass containers wrapped with aluminium foil and stored for six months in a stability chamber under three different conditions: room temperature (25 ± 2 °C), accelerated conditions (40 ± 2 °C / 75 ± 5% RH), and refrigerated conditions (4 ± 1 °C). At the end of the first, second, third, and sixth months, samples were withdrawn and analysed for in-vitro drug release, pH, drug content, and entrapment efficiency.[36]

Microsponges for topical delivery

Microsponges are extensively employed in topical drug delivery systems because of their capacity to entrap active pharmaceutical ingredients and release them in a controlled and sustained manner. They improve the stability, bioavailability, and therapeutic performance of the incorporated drugs, thereby minimizing adverse effects and enhancing patient adherence. By shielding sensitive drugs from degradation and enabling prolonged release, microsponges

are particularly suitable for the management of chronic dermatological disorders. In addition to therapeutic benefits, microsponges enhance the aesthetic qualities of topical formulations by providing a non-greasy feel and promoting efficient skin absorption without causing irritation. They are widely incorporated into products such as acne medications, anti-aging formulations, and sunscreens. Moreover, microsponges facilitate site-specific drug delivery, ensuring that the active agent is released directly at the target site, which optimizes therapeutic outcomes. Compared with conventional topical dosage forms such as creams, lotions, ointments, and gels, microsponges offer distinct advantages. These polymer-based porous microspheres can encapsulate a wide range of active substances, including emollients, fragrances, sunscreens, and anti-inflammatory agents. Unlike traditional formulations that often exhibit limited drug release and inadequate skin penetration, microsponges prevent rapid drug removal from the skin, resulting in prolonged residence time and improved delivery efficiency. Their non-greasy nature further enhances patient comfort, and they can be easily incorporated into various topical formulations. By addressing challenges such as poor diffusion, microsponges enable more effective therapy with reduced side effects.[37]

Microsponges for oral delivery

In oral drug delivery, microsponges enable controlled and prolonged release of active substances, thereby maintaining sustained therapeutic action. They improve the bioavailability of poorly water-soluble drugs by enhancing dissolution and absorption within the gastrointestinal tract. In addition, microsponges safeguard labile drugs from degradation in acidic gastric conditions, helping to preserve their stability. By reducing fluctuations in drug levels, these systems minimize adverse effects and promote better patient adherence. They can also be designed to deliver drugs to specific regions of the gastrointestinal tract for localized therapy. The sustained-release nature of microsponges lowers dosing frequency, making treatment regimens more convenient. Consequently, they are incorporated into oral formulations of drugs such as analgesics, antibiotics, and vitamins. Microsponges represent an advanced approach to controlled drug delivery, offering notable benefits over other extended-release systems such as matrix tablets, osmotic pumps, and liposomes. Unlike matrix tablets, which may exhibit inconsistent release due to factors like food intake and gastrointestinal transit time, microsponges provide more uniform and predictable drug release. Compared with osmotic pump systems, which may encounter issues such as dose dumping, microsponges demonstrate greater safety and formulation stability. They also overcome the drawbacks of ion-exchange resins, whose performance depends on the ionic

environment of the gastrointestinal tract, as well as conventional microencapsulation techniques that often lack precise control over release rates. Structurally, microsponges are highly porous, spherical microparticles with small pore sizes, rendering them self-sterilizing and capable of entrapping large amounts of drug. [38]

CONCLUSION

The present review concludes that the Microsponge Topical Delivery System (MTDS) is a notable innovation in dermatological and cosmetic drug delivery, providing controlled and prolonged release of active agents, improved formulation stability, and a reduction in adverse effects. The distinctive porous architecture of microsponges enables efficient drug loading, site-specific delivery, and decreased skin irritation, making them particularly suitable for topical applications such as acne management, anti-aging products, and wound care. Therefore, microsponge-based drug delivery technology is expected to evolve into a valuable and versatile matrix system for a wide range of therapeutic applications in the future.

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