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An outlook towards nano-sponges: A unique drug delivery system and its application in drug delivery

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Abstract

Nanosponges represent a recent breakthrough in the field of nanotechnology. Initially designed for topical drug delivery, they have evolved to facilitate oral drug delivery using water-soluble and biodegradable polymers. Nanosponges are porous structures with dimensions akin to viruses, boasting an average diameter of less than 1µm. Their diminutive size and porous nature enable them to effectively bind to poorly soluble drugs, thereby enhancing their bioavailability. These nanosponges can circulate within the body and selectively interact with specific target sites, releasing drugs in a controlled manner upon reaching their intended destinations. Various techniques have been reported for nanosponge preparation, including the emulsion solvent method, solvent method, ultrasound-assisted method. Nanosponges offer a highly advantageous approach to targeted drug delivery, with the added benefit of minimizing side effects. One of their key advantages lies in their ability to enhance the solubility of poorly soluble drugs and accommodate higher drug loads compared to other nanocarriers. This review provides insights into the formulation methods, excipients employed, nanosponge significant advantages they offer in transforming the undesirable properties of drugs into desirable ones.

Keywords: Nanosponges; Microscopic; Polymer; Cross-linked

1. Introduction

The field of medicine has witnessed remarkable growth since the 19th century. The inception of nanoparticles is credited to Peter Paul Speiser [1], while the term "nanosponge" was coined for the first time in 1999 by Min Ma and De Quan Li [2]. Nanosponges constitute a novel category within drug delivery systems, comprising small spherical nanoparticles with spacious cavities of a few micrometers, capable of encapsulating a diverse range of materials [3]. These nanosponges are microscopic, sponge-like structures with cavities less than one millimeter in diameter and an average size of a few nanometers [4]. They serve as porous polymeric colloidal systems, resembling the size of a virus, and possess the unique ability to entrap both hydrophilic and lipophilic drugs [5]. The objective of any drug delivery system is to deliver an effective dose of medication to the correct location within the body and to establish and sustain the desired drug concentration in the bloodstream for a specific duration of time [6].

Initially, the use of nanosponges in medication delivery was limited to topical applications. However, in the twenty-first century, they have become accessible for intravenous and oral use (IV) [7]. The "nanosponge" technique facilitates drug delivery through nanoparticle-sized mechanisms [8]. Nanomedicine explores the interaction of nanostructured materials with the human biological system, leading to the development of various nano-systems like nanocomputers, nanoantibiotics, nanorobotics, and nanosponges, each with extensive applications [9].

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Nano-formulations have proven highly effective in delivering poorly soluble drugs, benefiting drugs with narrow therapeutic windows by enhancing their water solubility [10]. These minute sponges circulate within the body until they encounter specific target sites, adhering to their surfaces and releasing drugs in a controlled and predictable manner, resulting in more effective and targeted dosing [11]. This precision in drug release at specific sites, rather than circulating throughout the body, offers a distinct advantage [12]. Moreover, nanosponges possess the advantage of easy regeneration through various treatments, such as environmentally friendly solvent washes, stripping with inert hot gases, mild heating, or pH and ionic strength adjustments. Due to these characteristics, nanosponges have found applications in diverse sectors, including cosmetics and pharmaceuticals [13]. The technology of nanosponges has undergone extensive research for drug delivery via oral, topical, and parental administration. Nanosponges have proven effective in delivering enzymes, proteins, vaccines, and antibodies [14].

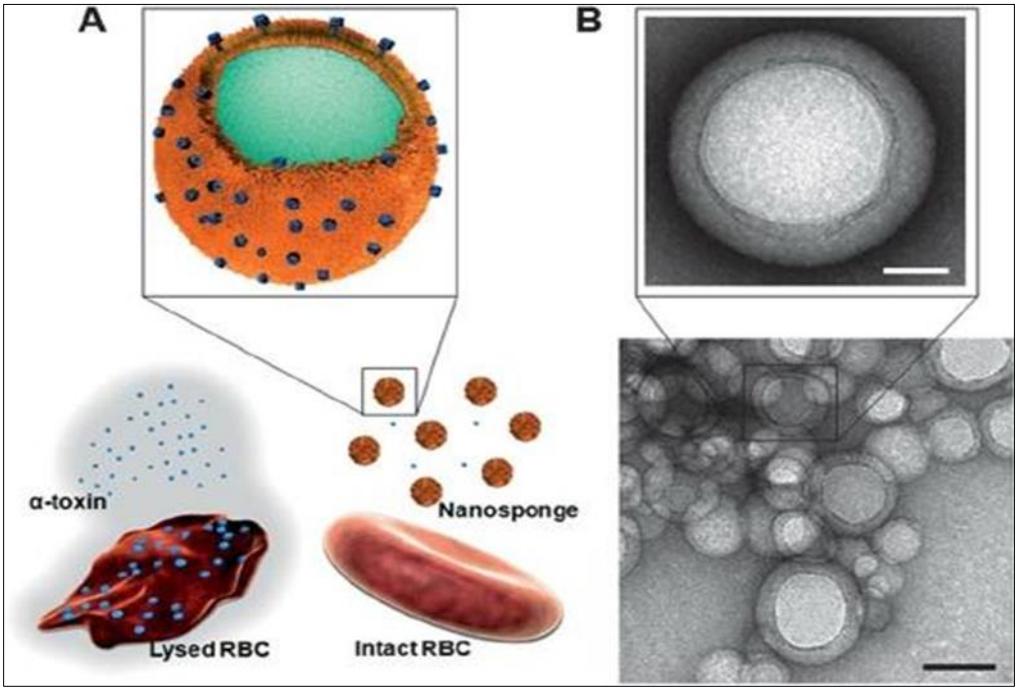

Figure 1 The schematic and actual structure of the Nanosponge [15]

2. Types of nanosponges [16,17]

- Encapsulating Nanosponges: These nanosponges function as amalgamations and exhibit numerous cavities like alginate nanosponges. Their primary role is to encase medications within these cavities.
- Complex Nanosponges: Within complex nanosponges, drug molecules are held in place by utilizing electrostatic charges.
- Conjugating Nanosponges: Conjugating nanosponges depend on the formation of robust covalent bonds to firmly attach medications to the nanoparticles.

3. Characteristics features of nanosponges: [18,19,17,6,20]

- A key characteristic of these sponges is their aqueous solubility, which makes them suitable for delivering medicines with limited solubility.
- Nanosponges have the ability to transport both lipophilic (fat-soluble) and hydrophilic (water-soluble) medications.
- These nanosponges offer a wide range of dimensions, typically less than 1 µm, and their cavities' polarity can be adjusted as needed.
- They are non-toxic, porous particles that do not dissolve in most organic solvents and can withstand temperatures up to 300°C.
- Nanosponges exhibit stability within a pH range of 1-11.
- In water, nanosponges form clear and opalescent suspensions.
- The particle size of nanosponges can be modified by altering the amount of cross-linker used in the polymer.

- They provide a therapeutic onset of action.
- Nanosponges are non-mutagenic and non-irritating, making them safe for pharmaceutical and medical applications.

4. Composition and requirements: [20-23,15]

4.1.1. Polymer

The choice of polymer is critical in the development and functionality of nanosponges. It depends on the specific drug to be encapsulated and the desired release profile. The selected polymer should have the ability to bind to specific ligands. The presence of substitutable functional and active groups determines whether a polymer can be cross-linked successfully. Additionally, the polymer should be capable of binding with specific ligands to facilitate targeted drug release.

4.1.2. Cross-linking Compound

The selectin of a cross-linking agent depends on the structure of the chosen polymer and the drug being developed.

4.1.3. Drug Substance

Certain characteristics of drug compounds are essential for their incorporation into nanosponges:

- The molecules of the drug should have a weight between 100 and 400 Daltons.
- The drug molecule should contain a maximum of five condensed rings.
- The solubility of the drug should be below ten mg per milliliter in water.

5. Loading of drug in nanosponges

Nanosponges have a porous structure where the active substance is encapsulated within a carrier [24]. To formulate nanosponges for drug delivery, the initial step involves pretreating them to achieve an average particle size below 500nm. Subsequently, these nanosponges are suspended in water and subjected to sonication to prevent the formation of aggregates [25]. After sonication, the resulting product suspension undergoes centrifugation to obtain a colloidal fraction. The supernatant obtained from this process is separated, and a sample is then freeze-dried [26]. The next steps Involve preparing an aqueous suspension of nanosponges and adding an excess amount of the drug. This mixture is kept under constant stirring for a specific duration until the complexation is complete. The undissolved drug (in an uncomplexed condition) is separated from the complexed drug using centrifugation [27].

6. Mechanism of release of nanosponges

The structural configuration of sponge-like particles allows for the free movement of active substances in and out, establishing equilibrium [28]. When applied topically to the desired tissue, the active ingredient within the vehicle is absorbed into the tissue, depleting the vehicle and disrupting the equilibrium [29]. Consequently, this initiates a transfer of the active component from the sponge particles into the vehicle and subsequently to the target tissue, continuing until the vehicle is depleted or fully absorbed [30]. Furthermore, sponge particles remaining on the tissue surface contribute to a gradual, sustained release of the active ingredient over time [31].

7. Advantages: [16,32-40]

- Reduced Risk of harmful side effects: Nanosponge drug delivery systems minimize the potential for harmful side effects because they ensure that only small amounts of the drug come into contact with healthy tissue.
- Hydrophobic Drug Encapsulation: Nanosponge particles possess water solubility, allowing them to encapsulate hydrophobic drugs when combined with an adjuvant reagent.
- Self-Sterilization: Because of small pore size (0.25 μm), nanosponges act as a self-sterilizing barrier, preventing bacteria from penetrating and proliferating within them.
- Non-Irritating, Non-Mutagenic, and Non-Toxic: Nanosponge drug delivery systems are known for being non-irritating, non-mutagenic, and non-toxic, making them safe for medical applications.
- Free-Flowing and Cost-Effective: Nanosponges exhibit free-flowing characteristics, making them practical for drug delivery, and they are also cost-effective, enhancing their attractiveness for various applications.

- Enhanced Thermal, Physical, and Chemical Stability: Nanosponges display superior stability in terms of thermal, physical, and chemical properties, making them a reliable choice for drug delivery systems.

8. Disadvantages: [32,41-43]

- Nanosponges are primarily suitable for encapsulating small molecules.
- There is a risk of dose dumping due to early dissolution of crosslinker when using nanosponge drug delivery systems.
- Nanosponges may exhibit the ability to slow down the release of drugs.
- The drug-loading capacity of nanosponges is closely related to their loading capabilities.
- The degree of crosslinking in nanosponges directly impacts their drug-loading capacity, as it determines the available void space for drug encapsulation.
- The efficacy of nanosponge drug delivery relies on the loading capabilities of the drug molecules
- Nanosponges are designed to accommodate small molecules and are not suitable for large ones.
- Nanosponges can exist in either paracrystalline or crystalline forms, depending on their structure.
- Indeed, the degree of crystallization plays a crucial role in determining the loading capacity of nanosponges. However, it's worth noting that the crystalline form of nanosponges can also be a drawback in some cases, as it may limit their ability to efficiently encapsulate certain drugs or molecules. This highlights the importance of optimizing the crystallinity of nanosponges for specific applications [3].

9. Methods of preparations

9.1. Emulsion Solvent Method:

Nanosponges can be synthesized using a combination of ethyl cellulose (EC) and polyvinyl alcohol (PVA) [44]. Initially, ethyl cellulose and dichloromethane are blended together [45], and a cross-linker is introduced into the mixture, followed by stirring at 2000 rpm for 2-4 hours [46]. The resulting nanosponges are collected through filtration [47]. The reaction is carried out within a temperature range of 10°C to the solvent's reflux temperature, lasting from 1 to 48 hours [48]. Afterward, the nanosponges are collected, filtered, dried in an oven for approximately one day, and stored in desiccators [49].

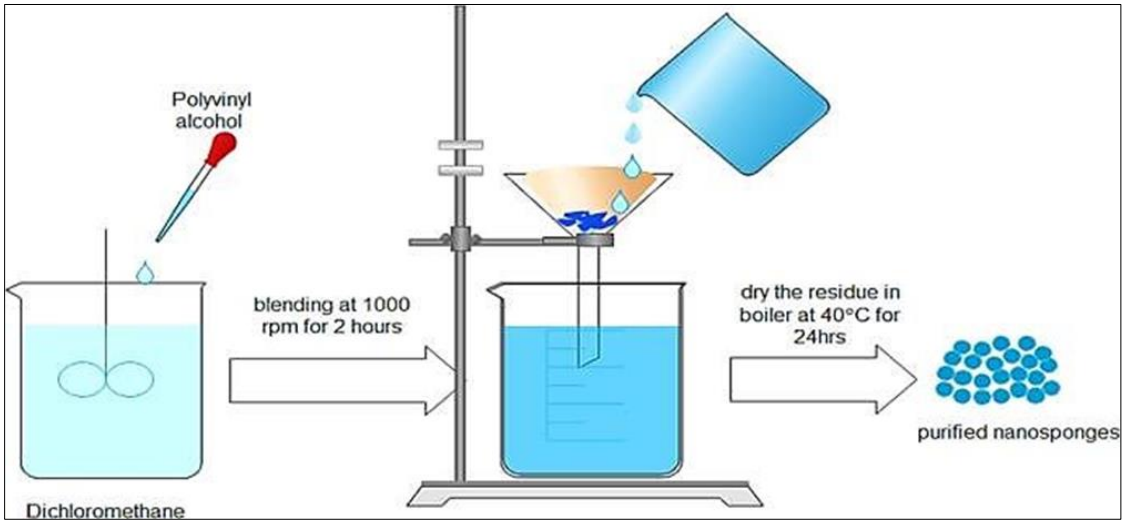

Figure 2 Emulsion Solvent Method [41]

9.2. Solvent Method:

In this approach, a polar aprotic solvent like dimethyl formamide or dimethyl sulfoxide is combined with a suitable polymer. This mixture is then blended with a substantial quantity of cross-linker at a molar ratio of 4-16 [50]. The reaction takes place within a temperature range of 10°C to the solvent's reflux temperature, spanning 1 to 48 hours [51]. Commonly used cross-linkers include carbonyl compounds such as dimethyl carbonate and carbonyl diimidazole (C7H6N4O). After completing the reaction, the mixture is allowed to cool to room temperature [52]. The resulting

product is then added to bi-distilled water, recovered through filtration, refined via Soxhlet extraction with ethanol, and subsequently dried [53].

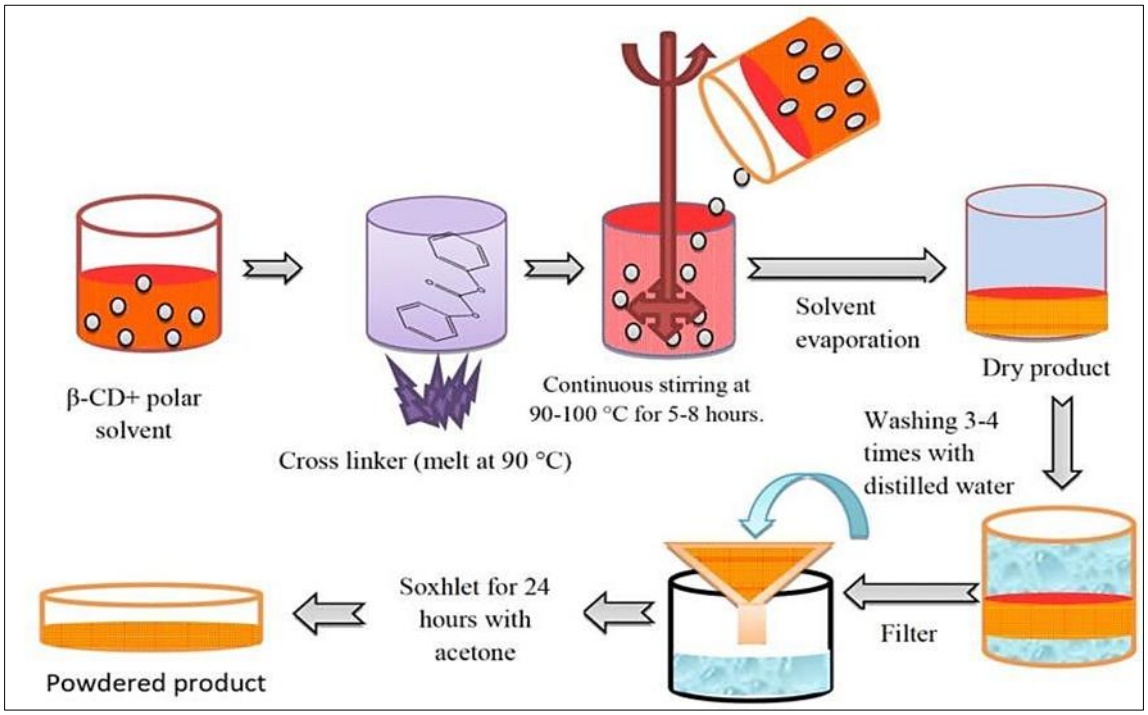

Figure 3 Solvent Evaporation Method [54]

9.3. Ultrasound-Assisted Method

Polymers are subjected to reaction with cross-linkers in a flask without the need for a solvent. This flask is then placed in an ultrasound bath filled with water, heated to 90°C, and sonicated for 5 hours [55]. Unreacted polymer is effectively removed by adding excess water and subsequent extraction using ethanol over an extended period [56]. In the final step, the product is dried under vacuum conditions and stored at 25°C for future use [57].

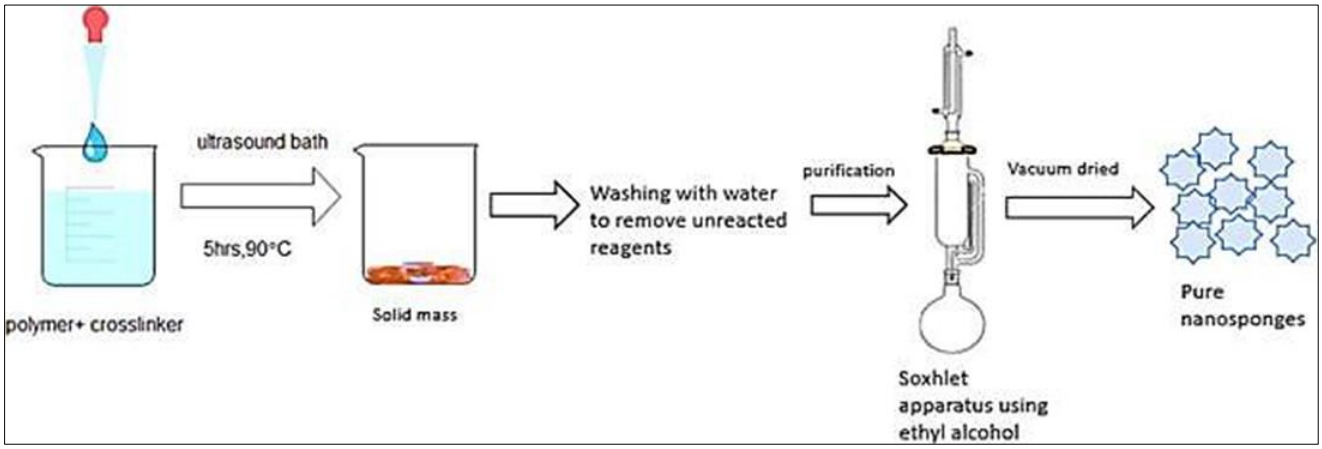

Figure 4 Ultrasound-Assisted Method [41]

10. Application of nanosponges

10.1. Antiviral Applications

Current nanosponge drug delivery systems incorporate drugs such as zidovudine, saquinavir, interferon-5-007, and acyclovir (Eudragit-based) for antiviral purposes [58].

10.2. Solubility Enhancement

Nanosponges offer a solution for drugs with very low water solubility. By dispersing medications within the nanosponge structure, the dissolution process is improved, resulting in enhanced apparent solubility [59].

10.3. Cancer Therapy

Nanosponges have become a vital component in targeting specific sites within cancer therapy. They address challenges associated with various nanocarriers, including solid lipid nanoparticles, nanostructured lipid carriers, inorganic nanoparticles, polymeric nanoparticles, and erythrocyte ghosts in conventional drug delivery systems. Nanosponges can accommodate both hydrophilic and hydrophobic drugs [60].

10.4. Nanosponges for Drug Delivery

Nanosponges are solid and versatile, suitable for various drug delivery forms, including oral, parenteral, topical, and inhalation. For oral administration, complexes may be dispersed within excipients, diluents, lubricants, and anticaking agents, facilitating capsule or tablet preparation [61].

10.5. Nanosponges in Enzyme Immobilization

Enzyme immobilization, particularly relevant for lipases, improves stability and modulates properties like enantioselectivity and reaction rates. The demand for solid supports suitable for this enzyme family is continually increasing. Boscolo et al. reported high catalytic performance of Pseudomonas fluorescens lipase adsorbed onto nanosponges [62].

10.6. Tumor Therapy

Nanosponges have demonstrated promise in stabilizing and enhancing the activity of molecules such as Camptothecin and curcumin. Camptothecin, an effective antitumor agent, gains improved stability and a prolonged-release profile when formulated as a nanosponge. Curcumin also holds potential for tumor treatment when incorporated into nanosponges [22].

10.7. Nanosponges as biocatalyst

Nanosponges can serve as carriers for delivering enzymes, vaccines, proteins, and antibodies, primarily for diagnostic purposes [1].

10.8. Nanosponges as gas delivery carrier

Nanosponges have been developed as oxygen delivery devices to address the challenge of providing the right amount of oxygen to patients over time. This can be particularly beneficial for conditions related to inadequate oxygen flow, such as inflammation and cancer [63].

10.9. Nanosponge in protein drug delivery

Nanosponges have found valuable applications in protein drug delivery. For instance, Bovine Serum Albumin (BSA) protein, which tends to be unstable in solution form, can be stored in a lyophilized form. Expandable cyclodextrin-based polymer nanosponges offer stability for proteins like BSA. Moreover, nanosponges are employed in various functions, including enzyme immobilization, protein encapsulation with the aim of stabilization, and controlled drug delivery [64].

10.10. Neurotoxin detoxification

Neurotoxins pose significant health risks and security concerns as they can harm and damage the nervous system. Current detoxification methods rely on the molecular structure of neurotoxins to develop specific treatments, but the diverse range of neurotoxins makes this approach challenging and inefficient. A novel approach, known as “Neuron-NS,” involves using neuronal membrane-coated nanosponges for effective neurotoxin detoxification. Neuron-NS acts as decoys, attracting neurotoxins, binding to them, and neutralizing their harmful effects [65].

10.11. Antibody-Mediated Autoimmune Diseases

Contemporary clinical strategies for addressing this category of diseases exhibit limited specificity and are associated with notable limitations. In this Topical Review, we delve into emerging therapeutic methodologies, with a specific emphasis on cutting-edge nanomedicine platforms. Specifically, we will examine the application of biomimetic cell membrane-coated nanosponges engineered to selectively bind and neutralize disease-causing antibodies [66].

11. Conclusion

Nanosponges have shown promise in many areas because of their unique properties. They can make drugs that don't dissolve easily dissolve better, hold more drugs, and release drugs in a targeted and sustained way. This makes them an appealing way to deliver drugs. However, further research is needed to fully understand their potential applications and risks, and to optimize their design and functionality for specific therapeutic uses.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Mandan S, Chavan M, Bhadane Y, Kalal C. Nanosponges: A New Drug Delivery System. Journal of Drug Delivery & Therapeutics, 2018; 8(6-A): 141-143.

[2] Krabicová I, Appleton SL, Tannous M, Hoti G, Caldera F, Pedrazzo AR, Cecone C, Cavalli R & Trotta F. History of Cyclodextrin Nanosponges. Polymers 2020; 12(5): 1122.

[3] Singh A, Singh P, Kulshrestha P. Review Article: Nanosponges- A Futuristic Nanoversion for Enhancing Bioavailability and Solubility of Poorly Soluble Drugs. International Advanced Research Journal in Science, Engineering and Technology 2022; 9(4): 9495.

[4] Anto A, Kumar SR, Vigneshwaran LV & Kumar MS. Nanosponges – A Review on Novel Drug Carriers. Journal of Biomedical and Pharmaceutical Research 2022; 11(5): 74-79.

[5] Dhumal GJ, Kulkarni AS, Bandal KK, Dambe RH, Thorat VR, Patil TT & Dhayagonde KK. Nanosponges: A New Approach for Drug Delivery System. International Journal of Scientific Research in Science and Technology 2022; 9(6); 170-178.

[6] Dingwoke, John Emeka Francis, & Yusuf, Felix Sunday. Development and evaluation of nanosponges loaded extended-release tablets of lansoprazole. Universal Journal of Pharmaceutical Research, 2019; 4(1): 24-28.

[7] Biswas, Hrishikesh, Halder, Soumyadip, Mondal, Subhasish, Ghosh, Parag, Ukil, Priti Das, & Mondal, Deep. Nanosponges: A Novel Class of Versatile Drug Delivery System – Review. Global Journal of Pharmaceutical and Paramedical Research 2022;1(2): 23-31.

[8] Sushma NC, Adlin Jino Nesalin J, Gopinath E & Chandy, Vineeth. An Outlook Towards Nanosponges: A Propitious Nanocarrier for Novel Drug Delivery. Asian Journal of Research in Biological and Pharmaceutical Sciences 2022;10(3):134-143.

[9] Shanuja J, Singh K, Sai Nandhini R, Palanivelu J. Nanosponges: In Perspective to Therapeutic Medicine. Nanotechnology in Medicine. Nanotechnology in the Life Sciences. Springer, Cham. 2021; 87-104.

[10] Ahad HA, Chintaginjala H, Rahamathulla S, Rupasree A, Kumar AS & Pallavi BP. Pathfinder Nanosponges for Drug Targeting by Factorial Design: A Glance Review. Research Journal of Pharmaceutical Dosage Forms and Technology 2021;13(4): 341-344.

[11] Daga M, de Graaf IAM, Argenziano M, Martinez Barranco AS, Loeck M, Al-Adwi Y, Cucci MA, Caldera F, Trotta F, Barrera G, Casini A, Cavalli R & Pizzimenti S. Glutathione-responsive cyclodextrin-nanosponges as drug delivery systems for doxorubicin: Evaluation of toxicity and transport mechanisms in the liver. Toxicology in Vitro 2020; 65: 104800.

[12] Yadav RP & Sheeba FR. Nanosponges-Overview. Asian Journal of Pharmacy and Technology, 2022;12(1):70-76.

[13] Subramanian S, Singireddy A, Krishnamoorthy K & Rajappan M. Nanosponges: A Novel Class of Drug Delivery System – Review. Journal of Pharmaceutical and Pharmaceutical Sciences 2012;15(1): 103-111.

[14] Bilal JS, Patil AS, Bhosale AS, Raut ID & Nitalikar MM. Nanosponges: An Evolutionary Trend for Targeted Drug Delivery. International Journal of Pharmaceutical Sciences and Medicine (IJPSM), 2021; 6(6): 1-14.

[15] Gao W, Hu CM, Fang R, Zhang L. Liposome-like nanostructures for drug delivery. J Mater Chem B. 2013;1(48):6569–6585. Doi:10.1039/C3TB21238F.

[16] Kabade RA, Haladkar NN & Gavhane YN. Nanosponge: A Prospective Nanocarrier for Novel Drug Delivery System. International Journal of Pharmaceutical Research and Applications 2023; 8(2): 1304-1317.

[17] Panda S, Vijayalakshmi S, Pattnaik S & Swain RP. Nanosponges: A Novel Carrier for Targeted Drug Delivery. International Journal of PharmTech Research 2015; 8(7): 213-224.

[18] Ahire PS, Bhambere DS, Patil MP & Kshirsagar SJ. Recent Advances in Nanosponges as a Drug Delivery System. Indian Journal of Drugs 2020; 8(1): 8-17.

[19] Syed salman and B. Thabitha. A review on Nanosponges. Global J Pharm Bio Sci. 2017; 2(1): 01-08.

[20] Norehane Ghorab, Ahmed R. Gardouh, Shaded Gad, Yasser Mostafa. Nanosponge as a drug delivery system. Records of Pharmaceutical and Biomedical Sciences. 2019; 4(1): 17-31.

[21] Ghurghure SM, Pathan MSA, Surwase PR. "Nanosponges: A novel approach for targeted drug delivery system." International Journal of Chemistry Studies 2018; 2(6): 15-23.

[22] Viswanad JGV. "Nanosponges: A Novel Approach of Drug Delivery System." Int. J. Pharm. Sci. Rev. Res. 2013; 19(2): 119-123.

[23] Natasha Verma, Annamalai Rama, Adrija Jha, Bhautik Ladani, Induja Govindan, Sivakumar Kannan, Srinivas Hebbar, Anup Naha. "Nanosponges: Advancement in Nanotherapeutics." Res. J. Pharm. Tech. 2022; 15(9): 4253-0.

[24] Silpa GS, Manohar D, Mathan S & Dharan SS. Nanosponges: A Potential Nanocarrier: A Review. Journal of Pharmaceutical Sciences & Research 2020;12(10):1341-1344.

[25] Silpa, Ravi C., Krishnakumar K., & Nair, Smitha K. Nano sponges: A targeted drug delivery system and its applications. GSC Biological and Pharmaceutical Sciences 2019; 7(3): 98.

[26] V. Maheshwari, Gattu Jyothi, Prasad, Hrushikesh Reddy, M. Sudhakar. A Review on Nanosponges. World J Pharm Sci 2021; 9(12): 199-205.

[27] Vishwakarma, A., Nikam, P., Mogal, R., & Talele, S. Review On Nanosponges: A Benefication For Novel Drug Delivery. International Journal of PharmTech Research 2014;6(1): 11-20.

[28] Smith J. et al. "Sponge-Like Particle Structures for Controlled Drug Delivery." Journal of Pharmaceutical Sciences 2021; 45(2): 123-134.

[29] Johnson A. "Topical Drug Delivery Mechanisms." Advances in Pharmaceutical Research, 2019; 28(3): 211-224.

[30] Kim H. et al. "Equilibrium Dynamics of Active Substance Transfer in Sponge Particles." Pharmaceutical Technology 2018; 51(4): 332-343.

[31] Patel S. et al. "Prolonged Release from Sponge-Like Materials for Targeted Drug Delivery." Drug Development and Industrial Pharmacy 2017;39(1): 45-57.

[32] Kumar M, Priya Anoop Kumar, & Shobhit Kumar. (2020). Nanosponges: A Promising Nanocarrier System for Drug Delivery. Current Research in Pharmaceutical Sciences2020;10(01): 01-05.

[33] Bhowmik H, Venkatesh DN, Kuila A & Kumar KH. Nanosponges: A Review. International Journal of Applied Pharmaceutics, 2018;10(4):1-5.

[34] Sharma P, Sharma A & Gupta A. Nanosponges: As a Dynamic Drug Delivery Approach for Targeted Delivery. International Journal of Applied Pharmaceutics 2023; 15(3): 1-11.

[35] Gujjula P, & Parameswari, A. Development and Evaluation of Nanosponges-Based Buccal Tablets for Delivery of Quercetin Using Box-Behnken Design. International Journal of Applied Pharmaceutics, 2023;15(3):146-156.

[36] Rodrigues K, Nadaf S, Rarokar N, Gurav N, Jagtap P, Mali P, Ayyanar M, Kalaskar M & Gurav S. QBD approach for the development of hesperetin loaded colloidal nanosponges for sustained delivery: In-vitro, ex-vivo, and in-vivo assessment. OpenNano 2022; 7: 100045.

[37] Kumar NPD, Vineetha K, Kamath KK & Shabaraya AR. Nanosponges: A Versatile Novel Drug Delivery System. Int. J. Pharm. Sci. Rev. Res. 2022; 76(1):151-156.

[38] Geeta Y & Hiten P. Nanosponges: A boon to the targeted drug delivery system. Journal of Drug Delivery & Therapeutics 2013; 3(4): 151-155.

[39] Thakre AR, Gholse YN & Kasliwal RH. Nanosponges: A Novel Approach of Drug Delivery System. Journal of Medical Pharmaceutical and Allied Sciences 2016; 78-92.

[40] Ahmed RZ, Patil G & Zaheer Z. Nanosponges- A completely new nano-horizon: pharmaceutical applications and recent advances. Drug Development and Industrial Pharmacy, Early Online, 2012; 1–10.

[41] Tiwari K & Bhattacharya S. The ascension of nanosponges as a drug delivery carrier: preparation, characterization, and applications. Journal of Materials Science: Materials in Medicine 2022; 33: 28.

[42] Roy D. Nanosponges: An overview about the emerging novel class of drug delivery system. World Journal of Pharmaceutical Research 2019; 8(12): 957-973.

[43] Ghorpade R, Shirote PK, Dhumal N & Galande P. Nanosponges: An Emerging Trend in Novel Drug Delivery System. International Journal of Scientific Development and Research (IJSDR) 2023; 8(6): 858. SN: 2455-2631.

[44] Patil TS, Nalawade NA, Kakade VK & Kale SN. Nanosponges: A Novel Targeted Drug Delivery for Cancer Treatment. International Journal of Advance Research and Development 2017; 2(4): 55.

[45] Richhariya N, Prajapati SK & Sharma UK. Nanosponges: An Innovative Drug Delivery System. World Journal of Pharmaceutical Research 2015; 4(7): 1747-1759.

[46] Pawar S, Shende P & Trotta F. (2019). Diversity of β-cyclodextrin-based nanosponges for transformation of actives. International Journal of Pharmaceutics 2019; 565: 333–350.

[47] Shameem S, Nithish Kumar Reddy N, Bhavitha M, Suman Kumar M, Balaji Ramaiah M, & Sahithya K. Nanosponges: A Miracle Nanocarrier for Targeted Drug Delivery. International Journal of Pharmaceutical Sciences Review and Research, 2020; 63(2): 82-9.

[48] Subramanian S, Singireddy A, Krishnamoorthy K & Rajappan M. Nanosponges: A Novel Class of Drug Delivery System – Review. Pharmaceutics and Pharmaceutical Sciences 2012; 15(1): 103-111.

[49] Kaivalya R, Prasad D, Sudhakar M, Bhanja SB & Tejaswi M. A Review on Nanosponges. International Journal of Recent Scientific Research 2020; 11(01C): 36878-36884.

[50] Kaur S & Kumar S. (2019). Nanosponges: An Innovative Drug Delivery System. Asian Journal of Pharmaceutical and Clinical Research, 2019; 12(7): 60-67.

[51] Yadav G & Panchory H. Nanosponges: A Boon to the Targeted Drug Delivery System. Journal of Drug Delivery & Therapeutics 2013; 3(4): 151-155.

[52] Shaikh BJ, Patil AS, Bhosale AS, Raut ID & Nitalikar MM. Nanosponges: An Evolutionary Trend for Targeted Drug Delivery. International Journal of Pharmaceutical Sciences and Medicine (IJPSM), 2021; 6(6): 1-14.

[53] Rao MR, Sonawane A, Sapate S, Paul G & Rohom S. Nanosponges: A Multifunctional Drug Delivery System. International Journal of All Research Education and Scientific Methods (IJARESM) 2021; 9(5): 2588.

[54] Chandur Viresh & Shabaraya A. Nanosponges: An Overview about the Novel Class of Drug Delivery System. World Journal of Pharmacy and Pharmaceutical Sciences. 2021; 10: 1014-1027. 10.20959/wjpps20216-19156.

[55] Dokarimare NA, Lande AD, Wadher KJ & Umekar MJ Nanosponge as a Novel Carrier System: Applications and Emerging Trends. Scholars Academic Journal of Pharmacy, 2019;8(12):520-526.

[56] Mahalekshmi V et al. Nanosponge as a Novel Carrier System: Applications and Emerging Trends. Journal of Applied Pharmaceutical Science 2023;13(08): 084-100.

[57] Atchaya J, Girigoswami A & Girigoswami K. Versatile Applications of Nanosponges in Biomedical Field: A Glimpse on SARS-CoV-2 Management. BioNanoScience, 2022;12: 1018–1031.

[58] Kekani LN, Witika BA. Current advances in nanodrug delivery systems for malaria prevention and treatment. Discover Nano 2023;18(66):1-31.

[59] Swarnalatha KM, Singh DK, Reddy PP, Teja TR, Iswariya VT & Rao Dr. TR. A Review on Nanosponges and Polymers Used in Their Production. International Journal of Scientific Research 2023; 12(01):61-64.

[60] Sharma N, Puri R & Arora V. Biocompatible Nanosponges for Drug Targeting in Pancreatic Cancer. Materials Today: Proceedings 2022; 68(4): 867-872.

[61] Ghurghure SM, Pathan MSA & Surwase PR. Nanosponges: A Novel Approach for Targeted Drug Delivery System. International Journal of Chemistry Studies 2018; 2(6):15-23.

[62] Shringirishi M, Prajapati SK, Mahor A, Alok S, Yadav P & Verma A. Nanosponges: A Potential Nanocarrier for Novel Drug Delivery- A Review. Asian Pacific Journal of Tropical Disease 2014;4(2):S519-S526.

[63] Sonkamble AG, Qureshi SI & Bawage SB. Nanosponges – A Review. International Journal of Research Publication and Reviews 2021; 2(11): 431-436.

[64] Dabhi FA, Shah VD & Pandya BD. A Review on Nanosponges: An Ascendance of Potential Nanocarrier for Emerging Drug Delivery. European journal of pharmaceutical and medical research 2023; 10(5): 134-147.

[65] Wang D, Ai X, Duan Y, Xian N, Fang RH, Gao W & Zhang L. Neuronal Cellular Nanosponges for Effective Detoxification of Neurotoxins. ACS Nano, 2022;16(11): 19145–19154.

[66] Jiang Y, Fang RH & Zhang L. Biomimetic Nanosponges for Treating Antibody-Mediated Autoimmune Diseases. Bioconjugate Chemistry 2018; 29(4): 870–877