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REVIEW: NANOSPONGES FOR TARGETED THERAPY

Shivkumar M. Sontakke*[1], Prajakta A. Kakade[1], Indrajeet D. Gonjari[1], Avinash H. Hosmani[1]

[1*]Department of Pharmaceutics, Government College of Pharmacy, Karad, Maharashtra, India.

ABSTRACT

Nanosponges are microscopic sponges that are roughly the size of viruses and may contain a wide range of medications. These microscopic sponges may move throughout the body until they come into contact with the precise target location, adhere to the surface and start to release the medication in a regulated and predictable way. For a given dosage, the medicine will work better since it can be delivered at the precise target place rather than circulating throughout the body. Their aqueous solubility is another crucial feature of these sponges, which enables the efficient application of these systems for medications with low solubility. We shall talk about the history of nanosponges in this review, Benefits and drawbacks, different varieties and techniques for making them, Current work carried out on Nanosponges and applications.

KEYWORDS

Nanosponges, Nanoporus polymers and Polymer- based nanosponges.

Author for Correspondence:

Shivkumar M. Sontakke,

Department of Pharmaceutics,

Government College of Pharmacy,

Karad, Maharashtra, India.

Email: shivsontakke6775@gmail.com

INTRODUCTION

Delivering medications to the right areas of the body and controlling their release to prevent overdosing has been a longstanding challenge for medical researchers focused on targeted drug delivery. A promising solution to these issues may lie in developing innovative molecules known as nanosponges. These are a unique class of materials made up of tiny particles with cavities just a few nanometers wide. These particles can encapsulate a wide range of substances, including both hydrophilic (water-soluble) and lipophilic (fat-soluble) compounds. Additionally, they can enhance the solubility of molecules not easily soluble in water[1].

Small mesh-like structures called nanosponges have the potential to completely change how many diseases are treated. According to preliminary research, this technology can deliver medications for breast cancer up to five times more effectively than traditional techniques[2]. The nanosponge has a naturally degradable polyester "backbone," or scaffold structure and is roughly the size of a virus. Small molecules known as cross-linkers, which have an affinity for certain polyester segments, are combined with the long polyester strands in the solution. To create a spherical shape with several pockets (or cavities) where medications can be kept, they "cross-link" sections of the polyester. Because of the polyester's predictable biodegradability, the medication may be delivered as it disintegrates in the body on a known schedule[2]. The drug molecules are encapsulated within the centre of the nanosponges, which are encapsulating nanoparticles. They can be categorised as encapsulating, complexing, or conjugating nanoparticles based on how they associate with pharmaceuticals. The nanosponges and nanocapsules are examples of the first category. Drug molecules are carried by alginate nanosponges, which are sponge-like nanoparticles with many pores. Nanoparticles are also encapsulated in nanocapsules like poly(isobutyl-cyanoacrylate) (IBCA). Their watery core has the ability to capture medicinal molecules. The second group consists of complexing nanoparticles, which use electrostatic charges to draw molecules to them. Conjugating nanoparticles, the third kind, form covalent connections with medications[3].

These are an innovative type of nanoparticles that are often derived from natural sources. In contrast to the other nanoparticles, they are porous, non-toxic, stable at temperatures as high as 300°C and insoluble in both water and organic solvents. Their 3D structure, which includes nanometric- sized chambers with configurable polarity, allows them to catch, transport, and selectively release a vast array of chemicals. Additionally, nanosponges have a notable benefit over typical nanoparticles: they may be readily regenerated by a variety of procedures, including light heating, stripping with hot gases that are relatively inert, washing with environmentally friendly solvents and altering the pH or ionic strength. Because of all these qualities, nanosponges have previously been used in a variety of application industries, including medicinal and cosmetic[4].

ADVANTAGES AND DISADVANTAGES

Advantages of Nanosponges

High drug loading capacity: They are useful for drug delivery because they can hold large amounts of drugs[14,15].

Targeted medication delivery: It may be made to target certain tissues or cells, which minimises adverse effects[15].

Regulated release: Able to sustain therapeutic levels by releasing medications in a regulated way[16].

Biocompatibility: Reduces toxicity by being built of biocompatible materials[17].

Stability: Can increase a drug's stability and prolong its shelf life[14].

Disadvantages of Nanosponges

Concerns about toxicity: The usage of specific compounds or leftover solvents may result in toxicity[15].

Problems with scalability: It might be difficult to increase production while preserving consistency[16].

Expensive: Producing them can be costly, which limits their accessibility[17].

Limited knowledge of long-term effects: It is yet unclear how nanosponges will affect the body in the long run[15].

Regulatory obstacles: Because of the intricacy of nanosponge technology, there may be regulatory obstacles[17].

STRUCTURE OF NANOSPONGES

The nanosponges are a network of polyester or a three-dimensional scaffold (backbone) that can break down spontaneously. To create nanosponges, these polyesters are combined with a crosslinker in a solution. In this case, the polyester decomposes in the body in a modest manner because it is typically biodegradable. When the scaffold of nanosponges

degrades, the loaded drug molecules are released in an adverse manner.

Silica or polymer framework

Offers the nanosponge's structural support. A variety of materials, including polymers (such PLGA, PEG and chitosan), silicates or silica, and hybrid materials (like polymer-silica composites), can make up this structure.

Pores

The framework's nanoscale gaps that permit drug loading and release. There are three types of pores: uniformly sized and dispersed, randomly sized and dispersed and customised to certain sizes and shapes.

Surface functional groups

Chemical groups that are affixed to the nanosponge's surface and have the ability to interact with target cells or medications. These groups may be targeting ligands (such as peptides or antibodies), hydrophilic (such as hydroxyl or carboxyl), or hydrophobic (such as alkyl or aryl).

MATERIAL USED

CATEGORIES OF NANOSPONGES

Nanosponges made of polymers

PLGA Nanosponges: These biodegradable and biocompatible nanosponges are made of poly(lactic-co-glycolic acid).

PEG Nanosponges: These hydrophilic, drug-delivery-suitable nanosponges are made of polyethylene glycol.

Chitosan Nanosponges: These biodegradable and biocompatible nanosponges are derived from the natural polysaccharide chitosan[9].

Nanosponges of silica

Mesoporous Silica Nanosponges (MSNs): These nanosponges are appropriate for drug delivery due to their high porosity and surface area.

Silica Nanospheres: These spherically shaped nanosponges are composed of silica.

Hollow Silica Nanospheres: These drug-delivery-capable nanosponges feature a hollow interior[10].

Nanosponges that are hybrid

Polymer-Silica Nanosponges: These nanosponges are made of both silica and polymeric materials. Lipid and polymeric components are combined in lipid-polymer nanosponges.

Protein-Polymer Nanosponges: A combination of polymeric and protein components, these nanosponges[11].

Nanosponges That Respond to Stimuli

pH-Responsive Nanosponges: These nanosponges can be utilised to transport drugs since they react to pH variations.

Temperature-Responsive Nanosponges: These nanosponges can be utilised to carry drugs and react to temperature changes.

Light-Responsive Nanosponges: These nanosponges are capable of delivering drugs and react to light[12].

Other Types of Nanosponges

Carbon Nanosponges: These nanosponges are made from carbon and have a high surface area.

Metal-Organic Framework (MOF) Nanosponges: These nanosponges are made from MOFs and have a high surface area and porosity.

Nanocellulose Nanosponges: These nanosponges are made from nanocellulose and are biodegradable and biocompatible[13].

METHOD OF PREPARATION

Solvent Method

Emulsion Solvent Method

Ultrasound -Assisted Synthesis

Melting method

Solvent Method

In particular, combine the polymer in concern with an appropriate solvent, such as dimethylformamide or dimethyl sulfoxide and then supplement this mixture with an additional quantity of their 4:16 accessible cross-linkers. The polymer process is kept at a temperature of 10 C for two days. The two most often used carbonyl cross-linkers are dimethyl carbonate and carbonyl diimidazole. The result is allowed to cool at room temperature after the reaction is accomplished, and then it is added into the mixture. Distilled water is collected, □ltered under an air oven, and puri□ed using a soxhlet device. After that, ethanol is added for further extraction. Repeat the drying procedure using

mechanical force and a vacuum to get a consistent white powder[18].

Emulsion Solvent Method

Ethyl cellulose and polyvinyl alcohol may be utilised in varying ratios to improve the drug-loading ability of nanosponges. The dispersion phase is created by dissolving the medication and ethyl cellulose in 20 ccs of dichloromethane. A continuous phase is produced when 150 millilitres of distilled water are used to dissolve polyvinyl alcohol. The continuous phase is dumped into the scattered phase. This mixture is then allowed to be agitated at 1000rpm for around two hours. The resulting nanosponges are gathered, dried for approximately a day in ovens, and stored in desiccators[19].

Ultrasound Assisted Synthesis

Using this method, polymers and cross-linkers are combined in an assay, which is then heated to 90°C in an ultrasonic bath filled with water and sonicated for five hours without the need of a solvent. Allow it to cool, then rinse with water to remove any remaining unreacted polymer. Purify via a lengthy soxhlet extraction process based on ethanol. Once the product has been vacuum-dried, store it at $25^{o}C$[20].

Melting Method

This process involves allowing crosslinkers and CDs to melt while all other ingredients are homogenised for five hours while being magnetically agitated. The solution is then allowed to cool and periodically washed to remove unreacted excipients and reaction byproducts[21,22].

Loading of the drug into nanosponges

Drug delivery nanosponges should undergo pre-treatment to achieve a mean particle size of less than 500nm. To prevent aggregates, suspend the nanosponges in water, sonicate them, and then centrifuge the solution to extract the colloidal fraction. After separating the supernatant, use freeze drying to dry the sample[23].

Prepare the nanosponge aqueous suspension, scatter any extra medication, and keep the suspension constantly stirred for the precise length of time needed for complexation. After complexation, use centrifugation to separate the uncomplexed (undissolved) drug from the complexed medication. Next, use solvent evaporation or freeze drying to produce the solid crystals of nanosponges[24].

The crystal structure of nanosponges is crucial for drug complexation. A study found that paracrystalline nanosponges exhibit different drug loading capacities compared to crystalline nanosponges. Specifically, drug loading is higher in crystalline nanosponges than in paracrystalline ones. In poorly crystalline nanosponges, drug loading occurs as a mechanical mixture rather than through the formation of an inclusion complex[25].

FACTORS INFLUENCE NANOSPONGE FORMATION

Polymer kind

The kind of polymer utilised can affect how nanosponges develop and function. The nanosponge's cavity size should be appropriate for complexation in order to hold a medication molecule of a specific size[26].

Drug types

Certain properties listed below are necessary for drug compounds to bind with nanosponges. A molecular weight of 100-400. There are less than five condensed rings in a drug molecule. Water solubility is less than 10mg/mL. The material has a melting point lower than 250°C[26].

The temperature

Drug/Nanosponge complexation may be impacted by temperature variations. The apparent stability constant of the drug/nanosponge complex often reduces as the temperature rises. This might be because the drug/nanosponge contact forces, such as van der Waal and hydrophobic forces, may decrease when the temperature rises[27].

Preparation technique

Drug/Nanosponge complexation may be impacted by the way the drug is loaded into the nanosponge. Although a method's efficacy varies depending on the medication and polymer, freeze drying has frequently been shown to be the most successful for drug complexation[28].

The extent of replacement

The kind, quantity, and location of the substituent on the parent molecule may have a significant impact on the nanosponge's capacity for complexation[27].

APPLICATIONS OF NANOSPONGES

Nanosponges have been identified as a new potential drug delivery system that may enter and pass through the skin. The delivery of biologics, such as proteins, peptides, enzymes, antibodies and vaccines, has also drawn more interest recently. Possess a broad variety of applications in pharmaceutical formulations because of their biocompatibility and adaptability. They can be used as excipients to make solid dispersions, tablets, capsules, pellets, granules, suspensions and other skin-care dosage forms. Enhanced product functionality and elegance, extended release, reduced irritability and enhanced thermal, physical, and chemical stability can all be achieved with nanosponges. Here are a few applications for nanosponges that highlight their versatility.

As Solubility enhancers

Nanosponges can increase the wetting and solubility of molecules with extremely poor water solubility. The dissolving process can be avoided by first molecularly spreading the drugs inside the nanosponge structure before releasing them as molecules. This can lead to an increase in the drug's perceived solubility. Many formulation and bioavailability problems may be resolved by improving a material's solubility and rate of dissolution and nanosponges have the potential to significantly improve the solubility of medications[28].

As Topical agents

An innovative technical development is the use of a nanosponge delivery system for the controlled release of topical medicines with delayed drug release and drug form retention on the skin. Among the medications that are readily produced as topical nanosponges are antibiotics, antifungals, and local anaesthetics. Active ingredients have the potential to penetrate the skin and result in rashes or other more serious side effects. On the other hand, this method allows for a steady and prolonged rate of release, reducing pain while maintaining efficacy. There are many different types of substances that may be used in a product, such as liquid, gel, cream, lotion, ointment, and powder. The antifungal medication econazole nitrate is administered topically to alleviate the symptoms of dermatophytosis, superficial candidiasis, Versicolour and skin infections. It is available as a cream, ointment, lotion, and solution[29].

Nanosponges as a sustained delivery system

The drug acyclovir is commonly used as an antiviral agent because of its effectiveness in treating herpes simplex virus infections. This does not include oral or parenteral. With the right concentration locations, acyclovir prescription formulations now available on the market may help the medicine reach its goal. Acyclovir's pharmacokinetics following oral administration are highly variable and its absorption in the digestive system is insufficient and slow[30].

Nanosponges in drug delivery

These will improve the aqueous solubility of medicines that are poorly soluble in water by forming inclusion complexes with a variety of drugs. These complexes can be used to produce disagreeable smells, solidify liquid chemicals and speed up the stability and breakdown of pharmaceuticals. It is claimed that the polymer-based nanosponges are three to five times more effective than direct injection at delivering medications to the intended location. They come from soil and can be converted into topical, parenteral, oral, or inhaled dose forms[31].

Nanosponges in enzyme immobilization

Enzyme immobilisation is especially crucial for lipases 51 since it improves their stability and influences characteristics like enantio selectivity and reaction rates. New solid supports that are suitable for the enzyme family are therefore becoming more and more necessary. Boscolo *et al*. found that Pseudomonas fluorescens lipase adsorbed on a novel kind of cyclodextrin-based nanosponges had remarkable catalytic capabilities[32].

Nanosponges for Cancer therapy

Distribution of anticancer medications is now one of the most challenging challenges in the pharmaceutical business because of their poor solubility. The nanosponge complex is three times easier to scale than direct injection. The Nanosponge complex loads a drug and releases a targeting peptide that firmly attaches to the cancer receptor's radiation-induced cell top layer. When nanosponges come into touch with a cancer cell, they adhere to its surface and begin to release drug molecules[33].

Nanosponges as potential Covid-19 treatment

The membranes from human cells that SARS-CoV-2 naturally targets are used to make these nanosponges. As long as SARS-CoV-2 viruses are present in the body, such as in the lungs, the nanosponges can attach and kill the viruses and cause clinical improvement in individuals afflicted with the virus. Cytokine neutralisation comes after SARS-CoV-2 neutralisation. These nanosponges can effectively protect the host cells against SARS-CoV-2 infection by vying with the host cells for viral binding[32].

HISTORY OF NANOSPONGES

Table No.1: History of nanosponges

S.No	Year	Event	Description	Reference
1	1990s	First generation nanosponges	Researchers began exploring nanosponges using silica and carbon nanotubes	5
2	2001	Nanoporous silica materials	Vallet-Regí *et al*, developed nanoporous silica materials for drug delivery	6
3	2005	Ordered mesoporous materials	Hartmann *et al*, developed ordered mesoporous materials for drug delivery	7
4	2009	Polymeric nanosponges	Uhrich *et al*, developed polymeric nanosponges using PLGA and PEG	8
5	2013	Targeted cancer therapy	Gao *et al*, developed pH-responsive nanosponges for targeted cancer therapy	9
6	2015	Biomedical applications	Zhang *et al*, reviewed nanosponges for biomedical applications	10
7	2018	Stimuli-responsive nanosponges	Chen *et al*, developed stimuli-responsive nanosponges for controlled drug delivery	11
8	2020	Personalized medicine	Li *et al*, reviewed nanosponges for personalized medicine	12
9	2022-24	Commercialization	Singh *et al*, discussed challenges and opportunities for commercializing nanosponge technology	13

Table No.2: Additives employed in nanosponges formulation

S.No	Polymers	Crosslinkers	Copolymers
1	Hyper cross linked Polystyrenes, Cyclodextrines and its derivatives like Methyl β-Cyclodextrin, Alkyloxycarbonyl Cyclodextrins, 2-Hydroxy Propyl β-Cyclodextrins[14].	Diphenyl Carbonate, Diarylcarbonates, Diisocyanates, Pyromellitic anhydride, Carbonyldiimidazoles, Epichloridrine, Glutarldehyde, Carboxylic acid dianhydrides, 2, 2-bis(acrylamido) Acetic acid and Dichloromethane[14].	Poly(valerolactone-allylvalerolactone) and Poly(valerolactone-allylvalerolactone-oxepanedione) and Ethyl Cellulose and PVA[14].

RECENT WORK ON NANOSPONGES

Table No.3: Recent work carried out on Nanosponges

S.No	Name of Treatment	Category of Drug	Name of Drug	Action	Uses	Ref.
1	Cancer Treatment	Anthracycline antibiotic Taxane	Doxorubicin Paclitaxel	Targeted delivery to cancer cells Enhanced solubility and bioavailability	Breast, lung, and liver cancer treatment Ovarian, breast and lung cancer treatment	33, 34
2	Antibiotics	Fluoroquinolone	Ciprofloxacin	Enhanced antibacterial activity	Urinary tract infections Respiratory tract infections	35
3	Anti-Inflammatory	NSAID	Ibuprofen	Improved bioavailability and reduced gastrointestinal side effects	Pain relief, fever reduction	36
4	Neurological Disorders	Acetylcholinesterase inhibitor	Rivastigmine	Improved cognitive function in Alzheimer's disease	Alzheimer's disease treatment	37
5	Cardiovascular Diseases	Statin	Atorvastatin	Enhanced bioavailability and reduced side effects	Cholesterol reduction cardiovascular disease prevention	38
6	Other Applications	Peptide hormone Fat-soluble vitamin	Insulin, Vitamin D	Oral delivery and improved bioavailability Enhanced bioavailability and improved bone health	Diabetes management Bone health, immune system support	39, 40

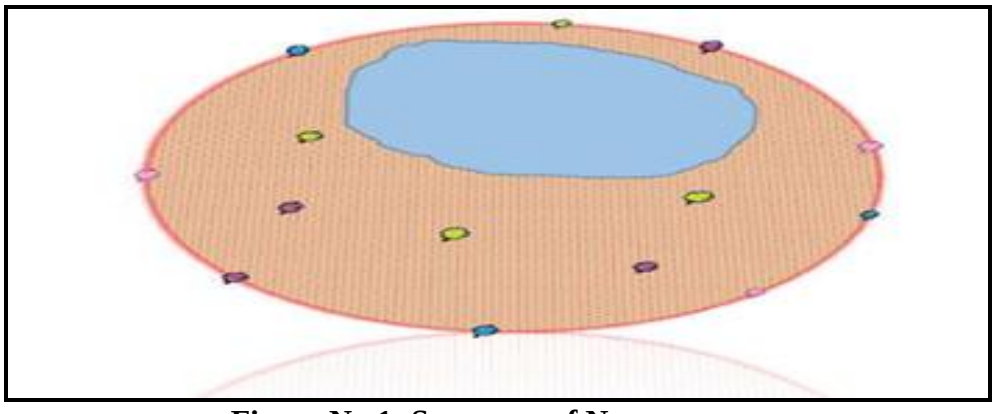

Figure No.1: Structure of Nanosponges

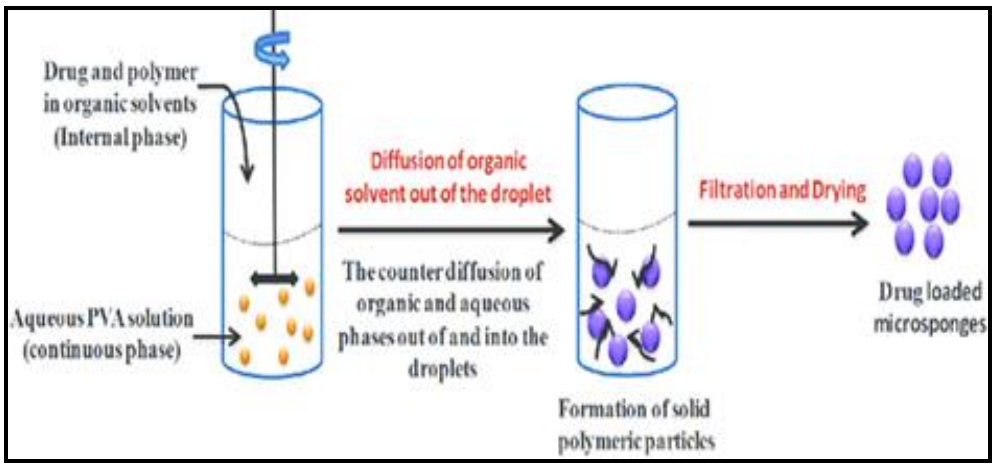

Figure No.2: Emulsion solvent method

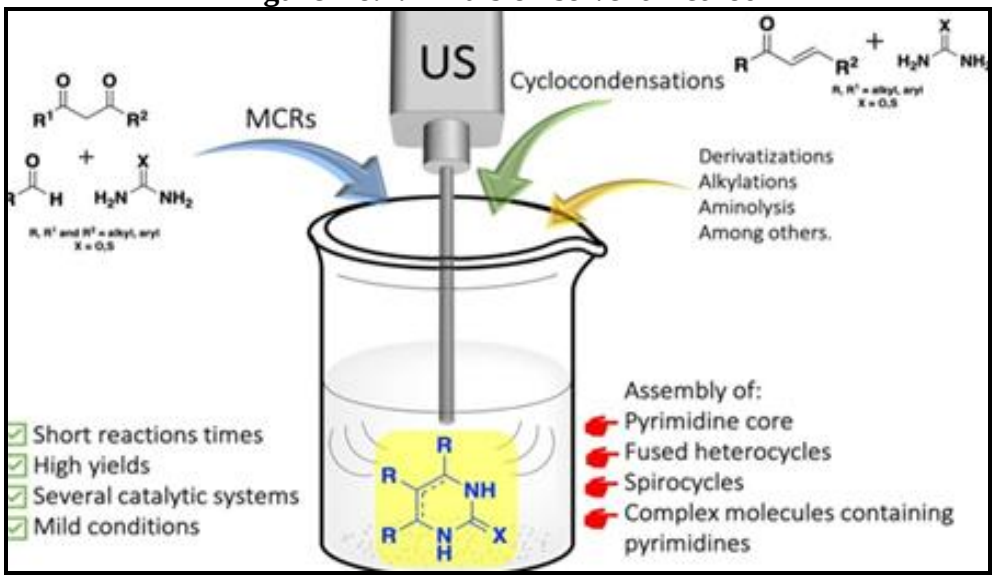

Figure No.3: Ultrasound assisted synthesis

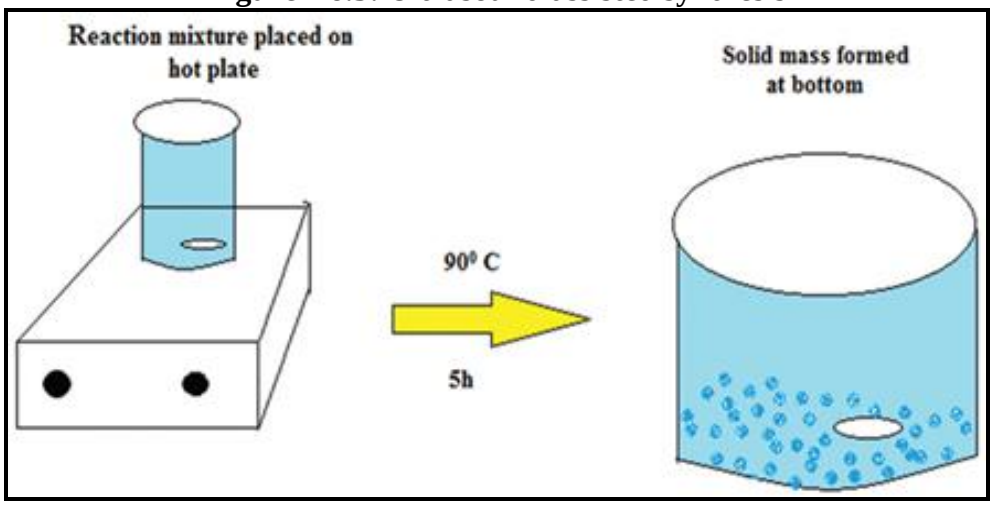

Figure No.4: Melting method

CONCLUSION

The earlier study found that nano sponges, a new kind of drug delivery vehicle, provide topical application with controlled drug administration. These tiny particles have the ability to disperse poorly soluble compounds and convey polar and slimy substances. They may be made in a variety of administration methods, such as topical and oral parenteral dose forms, because to their tiny particle size and spherical shape. Nano sponges will release the drug in a predictable and regulated way. Longer dose intervals and site-specific medication delivery are offered by the nano sponges. They are employed in a wide range of sectors, including the food industry, floriculture and oil clean-up. They have demonstrated a potent capacity to safeguard significant biomarkers in several illnesses, such as biocatalysts against physiochemical degradation and cancer. Nano sponges will play an important role in future advancements in drug delivery technologies.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

REFERENCES

1. Trotta F, Vallero R. Ultrasound-assisted synthesis of cyclodextrin-based nanosponges, *EP1 786 841 B1*, 2007.
2. David F. Nanosponge drug delivery system more effective than direct injection, *Phys Org*, 2010.
3. Trotta F, Tumiatti V. Cyclodextrin-based nanosponges as a vehicle for antitumoral drugs, *WO 2009/003656 A1*, 2009.
4. Liang L. Optimizing the delivery systems of chimeric RNA, DNA oligonucleotides beyond general oligonucleotide transfer, *Eur. J. Biochem*, 269(23), 2002, 5753-5758.
5. Vallet-Regi M, *et al*. Nanoporous silica materials as drug delivery systems, *Journal of Controlled Release*, 76(1-2), 2001, 39-51.
6. Hartmann M. Ordered mesoporous materials for drug delivery, *Chemistry of Materials*, 17(18), 2005, 4577-4593.
7. Uhrich K E, *et al*. Polymeric nanosponges for drug delivery, *Journal of Controlled Release*, 139(2), 2009, 137-145.
8. Gao W, *et al*. Targeted cancer therapy using pH-responsive nanosponges, *Small*, 9(2), 2013, 251-257.
9. Zhang Y, *et al*. Nanosponges for biomedical applications, *Journal of Controlled Release*, 206, 2015, 33-44.
10. Chen Y, *et al*. Stimuli-responsive nanosponges for controlled drug delivery, *Biomaterials Science*, 6(1), 2018, 14-25.
11. Li W, *et al*. Personalized medicine using nanosponges, *Advanced Healthcare Materials*, 9(1), 2020, 1901233.
12. Singh R, *et al*. Commercialization of nanosponge technology: Challenges and opportunities, *Journal of Pharmaceutical Sciences*, 109(1), 2020, 34-43.
13. Trotta F. Cyclodextrin nanosponges and their applications, cyclodextrins in pharmaceutics, *Cosmetics and Biomedicine*, 2011, 323-342.
14. Hasna E K, Junise V, Farhana M K, Shilpa K D. Review on nanosponges; A Nanotechnology drug delivery system, *Int. J. of Pharm. Sci*, 2(7), 2024, 1059-1065.
15. Thakre A R, Gholse Y N, Kasliwal R H. Nanosponges: A novel approach of drug delivery system, *J Med Pharm Allied Sci*, 78, 2016, 103-111.
16. Cyclodextrin based drug delivery systems, *Int J Res Ayurveda Pharm*, 2(5), 2011, 1520-1526.
17. Ahmed R Z, Patil G, Zaheer Z. Nanosponges-a completely new nano-horizon: Pharmaceutical applications and recent advances, *Drug Dev Ind Pharm*, 39(9), 2013, 1263-1272.

18. Singh D, Soni G C, Prajapati S K. Recent advances in nanosponges as drug delivery system: A review, *Eur J Pharm Med Res,* 3, 2016, 364-371.
19. Jenny A, Merima P, Alberto F, Francesco T. Role of β- cyclodextrin nanosponges in polypropylene photooxidation, *Carbohydrate Polymers*, 86(1), 2011, 127-135.
20. Lala R, Thorat A, Gargote C. Current trends in β- cyclodextrin based drug delivery systems, *Int J Res Ayur Pharm*, 2(5), 2011, 1520-1526.
21. Shankar S, Linda P, Loredana S, Francesco T, Pradeep V, Dino A, Michele T, Gianpaolo Z, Roberta C. Cyclodextrin-based nanosponges encapsulating camptothecin: Physicochemical characterization, stability and cytotoxicity, *Eur J Pharm Biopharm*, 74(2), 2010, 193-201.
22. Selvamuthukumar S, Rajappan M. Nanosponges: A novel class of drug delivery system-review, *Journal of Pharmacy and Pharmaceutical Sciences*, 15(1), 2012, 103-111.
23. Renu Kaivalya, Prasad D, Sudhakar M, Bhanja S B, Tejaswi M. A review on nanosponges, *Int J Recent Sci Res,* 11(01), 2020, 36878-36884.
24. Vaishnavi G. Gole, Patwekar S L, Ankush Doiphode, Ashwini Rode, Suleman Shaikh. A overview on nanosponges, *Asian Journal of Research in Pharmaceutical Sciences,* 12(3), 2022, 210-212.
25. Ghurghure S M, Pathan M S A, Surwase P R. Nanosponges: A novel approach for targeted drug delivery system, *Int J Chem Studies,* 2(6), 2018, 15-23.
26. Sehgal N, Gupta V, Kanna S. A review on nanosponges: A boon to targeted drug delivery for anticancer drug, *Asian J Pharm Clin Res,* 12(7), 2019, 1-7.
27. Amber V, Shailendra S, Swarnalatha S. Cyclodextrin based novel drug delivery systems, *J Incl Phenom Macrocycl Chem,* 62(1), 2008, 23-42.
28. Rajeswari C, Alka A, Javed A, Khar R K. Cyclodextrins in drug delivery: An update review, *AAPS pharm Sci Tech,* 6(2), 2005, E329-E357.
29. Thakre A R, Gholse Y N, Kasliwal R H. Nanosponges: A novel approach of drug delivery system, *J Med Pharm Allied Sci,* 78(92), 2016, 78.
30. Ranga Reddy K R, Uma Maheshwara Rao V. Nanosponges in drug delivery, *Trends Green Chem,* 7(1), 2021, 1-28.
31. Panda S, Vijayalakshmi S V, Pattnaik S, Swain R P. Nanosponges: A novel carrier for targeted drug delivery, *Int J PharmTech Res,* 8(7), 2015, 213-224.
32. Harsha G, Shaik N B, Lakshmi P K, Latha K. Formulation and evaluation of sertaconazole nitrate-loaded nanosponges for topical application, *Research Journal of Pharmacy and Technology*, 14(2), 2021, 895-902.
33. Zhang Q, Honko A, Zhou J, Gong H, Downs S. Cellular nanosponges inhibit SARS-CoV-2 infectivity, *Nano Letters*, 20(7), 2020, 5570-5574.
34. Mostafavi E, Iravani S, Varma R S. Nanosponges: An overlooked promising strategy to combat SARS-CoV-2, *Drug Discovery Today*, 27(10), 2022, 103330.
35. Narender B R, Rao P R. Formulation and evaluation of anticancer drug (doxorubicin) loaded nanosponges, *Indo American Journal of Pharmaceutical Research,* 9(12), 2019, 572-583.
36. Clemente N, Chiocchetti A, Caldera F, Trotta F, Benetti E, Annaratone L, Ribero S. Paclitaxel-loaded nanosponges inhibit growth and angiogenesis in melanoma cell models, *Frontiers in Pharmacology,* 10, 2019, 776.
37. Pyrak B, Gubica T, Szeleszczuk L. Exploring cyclodextrin-based nanosponges as drug delivery systems: Understanding the physicochemical factors influencing drug loading and release kinetics, *International Journal of Molecular Sciences*, 25(6), 2024, 3527.

38. Latif S, Ijaz Q A, Afzal H, Siddique M I, Hussain A, Arshad M S, Bukhari N I, Abbas N. Solubility and dissolution rate enhancement of ibuprofen by cyclodextrin based carbonate nanosponges, *Pakistan Journal of Pharmaceutical Sciences,* 34(3), 2021, 1045-1055.
39. Dighe S, Jog S, Momin M, Sawarkar S, Omri A. Intranasal drug delivery by nanotechnology: advances in and challenges for alzheimer's disease management, *Pharmaceutics,* 16(1), 2023, 58.
40. Khafagy E S, Motawee A O, Ghorab M M, Gardouh A R. Atorvastatin-loaded pro-nanolipospheres with ameliorated oral bioavailability and antidyslipidemic activity, *Colloids and Surfaces B: Biointerfaces,* 227, 2023, 113361.
41. Appleton S L, Tannous M, Argenziano M, Muntoni E, Rosa A C, Rossi D, Caldera F, Scomparin A, Trotta F, Cavalli R. Nanosponges as protein delivery systems: Insulin, a case study, *International Journal of Pharmaceutics,* 590, 2020, 119888.
42. Jampilek J, Kos J, Kralova K. Potential of nanomaterial applications in dietary supplements and foods for special medical purposes, *Nanomaterials,* 9(2), 2019, 296.

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