



# Nanosponges For Drug Delivery And Cancer Therapy: A Review

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## Abstract

The complicated chemical reactions involved in the production of the newer drug delivery systems have mainly impeded efforts to build successful targeted drug delivery systems for a prolonged duration of time. Nanosponges, a recently created colloidal system, have the potential to overcome issues with medication toxicity, decreased bioavailability, and drug release over a wide area because they can be modified to work with both hydrophilic and hydrophobic types of drugs. Nanosponges are small sized with a three-dimensional network having a porous cavity. They can be prepared easily by crosslinking cyclodextrins with different compounds. Due to Cyclodextrin's outstanding biocompatibility, stability, and safety, a number of Cyclodextrin-based drug delivery systems have been developed promptly. The nanosponge drug delivery system possesses various applications in various ailments such as cancer, autoimmune diseases, theranostic applications, enhanced bioavailability, stability, etc. This review elaborates on benefits and drawbacks, preparation techniques, factors affecting their preparation, characterization techniques, applications, and most current developments in nanosponges.

**KEYWORDS:** Tiny, Cyclodextrins, polymers, DNAzymes.

## Introduction

Nanosponges are tiny, porous particles that can encapsulate a variety of drugs. They are made from materials like cyclodextrins, which are cyclic oligosaccharides, and other polymers. Their unique structure allows them to improve the solubility and stability of drugs.

Nanosponges are mesh-like minute structures that can encapsulate a large variety of substances and medication molecules. They enhance the solubilization capacity of both water-soluble drugs and lipid soluble drugs and also possess a spherical colloidal nature. They increase the bioavailability of drugs with prolonged drug release. Because of their internal hydrophobic chambers and exterior hydrophilic branching, nanosponges' amphiphile nature enables them to carry therapeutic molecules that are both hydrophilic and hydrophobic. They are like a 3D network having a backbone of long-chain polyesters present in the solution along with crosslinkers that connect different parts of the polymer

## WHY NANOSPONES THEROPY?

- ❖ It is a type of encapsulating nanoparticle which is able to hold the drug molecule in the core
- ❖ The developments in bioinspired, self-catabolic DNAzyme nanosponges with controllable drug delivery behaviors and suitable gene silencing functions have been reported, thereby opening a new window in designing smart nanosystems with gene therapeutic and personalized biomedical commitments
- ❖ Nanosponges are colloidal system that can be modified to work with both hydrophilic and hydrophobic drug.

### • Importance of Nanosponges

□ **Environmental Cleanup:** Nanosponges can effectively capture and remove pollutants from water and air. Their high surface area and porosity enable them to absorb contaminants, including oils, heavy metals, and organic pollutants, making them valuable tools for environmental remediation.

□ **Medical Applications:** In medicine, nanosponges can be used for targeted drug delivery. Their ability to encapsulate drugs and release them at specific sites in the body helps to enhance the efficacy of treatments while minimizing side effects.

□ **Antimicrobial Properties:** Some nanosponges are engineered to have antimicrobial properties. They can be used in wound dressings, coatings for medical devices, and other applications to prevent infections and promote healing.

□ **Cancer Treatment:** Nanosponges are being explored for their potential in cancer therapy. They can be designed to deliver chemotherapeutic agents directly to cancer cells, thereby improving the precision of treatment and reducing damage to healthy tissues.

□ **Diagnostic Tools:** In diagnostics, nanosponges can be employed as contrast agents in imaging techniques. Their ability to enhance signal contrast improves the accuracy of diagnostic imaging, such as MRI or ultrasound.

□ **Energy Storage:** Nanosponges can be utilized in energy storage devices like batteries and supercapacitors. Their high surface area and structural stability contribute to better performance and longer lifespans of these devices.

□ **Water Filtration:** Due to their large surface area and absorbent properties, nanosponges can be used in advanced water filtration systems to remove contaminants and improve water quality.

□ **Cosmetic and Personal Care Products:** In the beauty and personal care industry, nanosponges are used to deliver active ingredients more effectively in skincare products, improving their efficacy and ensuring better skin absorption.

□ **Agriculture:** Nanosponges can be applied in agriculture to enhance the delivery of fertilizers and pesticides. This targeted delivery can reduce the amount of chemicals needed and minimize environmental impact.

## TYPES OF NANOSPONGES AND DRUG DELIVERY SYSYTEM

ype of Nanosponges	Material Structure/Features		Drug Delivery Applications		Advantages Challenges
<b>Polymeric Nanosponges</b>	Polymers (e.g., PEG, PLA)	Biodegradable, porous	Controlled release, targeting specific tissues	Biocompatible, customizable	Degradation issues, stability
<b>Silica Nanosponges</b>	Silica (e.g., mesoporous)	High surface area, tunable porosity	Delivery of hydrophilic and hydrophobic drugs	High loading capacity, stable	Potential toxicity, complex synthesis
<b>Carbon-Based Nanosponges</b>	Carbon (e.g., graphene oxide)	High surface area, functionalizable	Targeted drug delivery, imaging	High stability, strong drug interactions	Cost, potential cytotoxicity
<b>Metal-Organic Frameworks (MOFs)</b>	Metal ions + organic ligands	Highly porous, tunable composition	Delivery of small molecules, genes	High drug loading capacity, versatile	Stability, toxicity concerns
<b>Liposome-Based Nanosponges</b>	Lipids	Bilayer structure, hydrophilic core	Encapsulation of hydrophobic drugs	Biocompatible, can incorporate various drugs	Leakage, limited stability
<b>Dendritic Nanosponges</b>	Dendritic polymers	Branched structure, high surface area	Targeted drug delivery, gene therapy	High loading capacity, controlled release	Complex synthesis, cost
<b>Hydrogel Nanosponges</b>	Hydrogels (e.g., alginate)	Water-swollen, flexible	Delivery of proteins, peptides	Biocompatible, responsive to stimuli	Mechanical strength, degradation

### Fabrication Equipment

1. **Nanoprecipitators:** Used for the controlled precipitation of nanosponges from solutions. They ensure precise formation of nanoparticles with desired properties.
2. **Electrospinning Apparatus:** Utilized to produce nanofibers or nanosponges with specific morphologies. This method involves applying a high voltage to a polymer solution to create fine fibers.
3. **Sol-Gel Process Equipment:** Equipment for synthesizing nanosponges via the sol-gel process, which involves transitioning a solution into a gel phase to form porous structures.
4. **Freeze Dryer (Lyophilizer):** Used to remove solvents from nanosponges while preserving their structure through freeze-drying techniques.
5. **High-Pressure Homogenizers:** Employed for the production of uniform nanoparticles by applying high pressure to a solution, breaking down aggregates into nanoscale particles.

## Characterization Equipment

1. **Transmission Electron Microscope (TEM):** Provides detailed images of the internal structure of nanosponges, including size and morphology at the nanoscale.
2. **Scanning Electron Microscope (SEM):** Offers high-resolution imaging of the surface morphology and structure of nanosponges.
3. **Dynamic Light Scattering (DLS) Apparatus:** Measures the size distribution and stability of nanosponges in solution by analyzing fluctuations in light scattering.
4. **Surface Area and Porosity Analyzer (BET Analysis):** Determines the surface area and pore size distribution of nanosponges, crucial for understanding their adsorption properties.
5. **Fourier-Transform Infrared Spectroscopy (FTIR):** Analyzes the chemical composition and functional groups present in nanosponges.
6. **Nuclear Magnetic Resonance (NMR) Spectroscopy:** Provides detailed information about the chemical environment and structural characteristics of nanosponges.
7. **X-ray Diffraction (XRD):** Identifies the crystalline structure and phase of nanosponges by measuring the diffraction patterns of X-rays.

## Drug Delivery Testing Equipment

1. **In Vitro Release Testers:** Used to evaluate the release kinetics of drugs from nanosponges in simulated biological conditions.
2. **High-Performance Liquid Chromatography (HPLC):** Analyzes the concentration and purity of drugs released from nanosponges and assesses the stability of the drug.
3. **Cell Culture Systems:** Used to test the biological interactions, cytotoxicity, and efficacy of drug-loaded nanosponges in cultured cells.
4. **Animal Models:** Employed to study the in vivo behavior, pharmacokinetics, and therapeutic efficacy of drug-loaded nanosponges.

## Quality Control and Safety Equipment

1. **Particle Size Analyzers:** Measures the size distribution and ensures uniformity of nanosponges.
2. **Zeta Potential Analyzers:** Assesses the surface charge and stability of nanosponges in suspension.
3. **Thermal Gravimetric Analyzers (TGA):** Evaluates thermal stability and composition by measuring weight changes in nanosponges as they are heated.

## Design and Planning

- **Objective Definition:** Define the purpose of the nanosponges, such as for drug delivery, environmental cleanup, or other applications.
- **Material Selection:** Choose appropriate materials for the nanosponges, such as polymers, silica, carbon, or hydrogels, based on the desired properties and application.



## 2. Synthesis and Fabrication

- **Preparation of Precursors:** Prepare the starting materials or precursors required for the synthesis of nanosponges. This might involve dissolving polymers, preparing metal-organic frameworks, or other initial steps.
- **Fabrication Methods:** Employ various methods to create the nanosponges, including:
  - **Sol-Gel Process:** Transitioning a solution into a gel phase to form a porous structure.
  - **Electrospinning:** Using high voltage to create nanofibers that are then processed into nanosponges.
  - **Nanoprecipitation:** Controlled precipitation of nanosponges from a solution.
  - **Freeze Drying:** Removing solvents from a gel or solution to form a porous nanospongy structure.
- **Crosslinking:** If needed, crosslink the nanosponges to stabilize their structure and enhance their functionality. This might involve chemical reactions that link polymer chains.

## 3. Characterization and Quality Control

- **Size and Morphology:** Use Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) to analyze the size and surface morphology.
- **Surface Area and Porosity:** Measure surface area and pore size using BET analysis to assess the adsorption capabilities of the nanosponges.
- **Chemical Composition:** Analyze chemical composition and functional groups using Fourier-Transform Infrared Spectroscopy (FTIR) and Nuclear Magnetic Resonance (NMR) spectroscopy.
- **Stability and Charge:** Assess stability in suspension and surface charge using Zeta Potential Analyzers.

## 4. Functionalization

- **Drug Loading:** If the nanosponges are intended for drug delivery, load them with therapeutic agents or drugs. This process may involve dissolving the drug in a suitable solvent and allowing the nanosponges to absorb it.
- **Surface Modification:** Modify the surface of the nanosponges to enhance their interaction with specific biological targets or environmental pollutants. This can involve attaching ligands, antibodies, or other functional groups.

## 5. Testing and Evaluation

- **In Vitro Testing:** Evaluate the performance of drug-loaded nanosponges in cell culture models. This includes assessing cytotoxicity, drug release profiles, and cellular uptake.
- **In Vivo Testing:** Conduct animal studies to test the efficacy, safety, and pharmacokinetics of the nanosponges in a biological system.
- **Release Kinetics:** Perform in vitro release tests to determine the rate and extent of drug release from the nanosponges under simulated physiological conditions.

## 6. Application and Implementation

- **Application Integration:** Integrate the nanosponges into the intended application, such as drug delivery systems, environmental cleanup devices, or personal care products.
- **Regulatory Compliance:** Ensure that the nanosponges meet regulatory requirements and standards for safety and efficacy before commercialization.

## 7. Scaling Up and Manufacturing

- **Scale-Up:** Transition from laboratory-scale production to larger-scale manufacturing processes, ensuring that the synthesis and quality control processes are reproducible on a larger scale.
- **Manufacturing:** Set up manufacturing processes that can produce nanosponges in bulk, maintaining consistent quality and performance.

## 8. Monitoring and Optimization

- **Performance Monitoring:** Continuously monitor the performance of nanosponges in real-world applications and gather feedback for further improvement.
- **Optimization:** Make adjustments to the synthesis, functionalization, or application processes based on performance data to enhance the efficiency and effectiveness of the nanosponges.

### Objective of Nanosponges and Drug Delivery System :

- ♣ Enhance Drug Delivery Efficiency.
- ♣ Improve Environmental Remediation.
- ♣ Advance Medical Diagnostics.
- ♣ Optimize Material Properties for Various Applications.
- ♣ Ensure Safety and Biocompatibility

### Benefits of Nanosponges For Drug Delivery and Cancer Therapy :

#### 1. Enhanced Drug Delivery

- **Targeted Delivery:** Nanosponges can be engineered to deliver drugs precisely to specific cells or tissues, improving the effectiveness of treatments and reducing side effects.
- **Controlled Release:** They provide sustained or controlled release of drugs over time, improving therapeutic outcomes and reducing the frequency of dosing.

#### 2. Improved Environmental Remediation

- **Efficient Pollution Removal:** Nanosponges can effectively capture and remove a wide range of pollutants, including oils, heavy metals, and organic contaminants, from air, water, and soil.
- **High Surface Area:** Their large surface area and porous structure enhance their ability to adsorb and concentrate pollutants, leading to more efficient cleanup processes.

#### 3. Advanced Medical Diagnostics

- **Enhanced Imaging:** Nanosponges can be used as contrast agents in imaging techniques (e.g., MRI, ultrasound), providing better resolution and more accurate diagnostics.
- **Sensitive Detection:** They can improve the sensitivity and specificity of diagnostic tests by providing more precise detection of biomarkers or disease indicators.

#### 4. Versatile Material Properties

- **Customizable Features:** Nanosponges can be tailored to have specific physical and chemical properties, such as pore size, surface chemistry, and stability, making them suitable for various applications.
- **Multifunctionality:** They can be designed to perform multiple functions simultaneously, such as drug delivery and imaging, or pollutant removal and filtration.

#### 5. Biocompatibility and Safety

- **Minimal Toxicity:** Many nanosponges are designed to be biocompatible, reducing the risk of adverse reactions when used in medical applications.
- **Safe Degradation:** Biodegradable nanosponges break down into non-toxic byproducts, minimizing environmental and health risks.

#### 6. Enhanced Efficiency and Performance

- **High Efficiency:** Their high surface area and porosity enable more efficient adsorption, release, and interaction with target substances or cells.
- **Rapid Response:** Nanosponges can respond quickly to environmental changes or stimuli, making them effective in dynamic conditions.

#### 7. Cost-Effectiveness

- **Reduced Need for Reagents:** Efficient use of materials and high performance can lead to lower costs for drugs, environmental cleanup, or diagnostic procedures.
- **Long-Term Savings:** Improved effectiveness and reduced side effects can result in long-term cost savings in healthcare and environmental management.

#### PROTOCOLS

1. Objective Definition
2. Material Selection
3. Design and Fabrication
4. Characterization
5. Functional Testing
6. Biological Testing
7. Data Analysis
8. Documentation and Reporting
9. Application and Implementation

#### ADVANTAGES OF NANOSPONGES AND DRUG DELIVERY SYSTEM

- a) Targeted Drug Delivery
- b) Controlled and Sustained Release
- c) Enhanced Stability of Drugs
- d) High Drug Loading Capacity
- e) Biocompatibility and Safety
- f) Versatility in Drug Delivery
- g) Improved Patient Compliance
- h) Targeted Therapeutic Strategies

## Disadvantages of Nanosponges for drug delivery and cancer therapy

- a) Limited Targeting Precision
- b) Potential for Drug Resistance
- c) High Costs
- d) Complexity of Formulation
- e) Regulatory and Approval Challenges
- f) Complexity of Treatment Plans
- g) Psychological Impact: Mental Health Issues, Emotional Stress

## Nanosponges for Drug Delivery

### 1. Targeted Drug Delivery

- **Precision:** Nanosponges can be engineered to deliver drugs specifically to target tissues or cells, such as cancer cells, while minimizing effects on healthy tissues.
- **Functionalization:** Surface modifications can help direct nanosponges to specific cellular receptors or tissues, enhancing targeting accuracy.

### 2. Controlled and Sustained Release

- **Extended Duration:** Nanosponges can provide a controlled and sustained release of therapeutic agents over time, reducing the need for frequent dosing.
- **Customized Release Profiles:** They can be designed to release drugs in response to specific environmental conditions, such as pH or temperature changes.

### 3. Improved Drug Solubility and Stability

- **Enhanced Solubility:** Nanosponges can improve the solubility of poorly water-soluble drugs, leading to better bioavailability.
- **Protection from Degradation:** Encapsulation within nanosponges can protect drugs from degradation due to environmental factors, such as light or oxygen.

### 4. High Drug Loading Capacity

- **Efficient Delivery:** Nanosponges can hold a significant amount of therapeutic agents, allowing for high drug payloads and reducing the frequency of administration.

### 5. Reduced Side Effects

- **Localized Delivery:** By targeting drugs directly to the desired site, nanosponges can reduce off-target effects and minimize systemic toxicity.

## Nanosponges for Cancer Therapy

### 1. Targeted Delivery of Chemotherapy Drugs

- **Selective Targeting:** Nanosponges can deliver chemotherapy drugs directly to tumor cells, reducing the impact on healthy tissues and improving treatment efficacy.
- **Minimized Side Effects:** Targeted delivery can help mitigate the common side effects of chemotherapy, such as nausea and hair loss.

### 2. Enhanced Drug Penetration

- **Better Tumor Penetration:** Nanosponges can improve the penetration of therapeutic agents into tumor tissues, overcoming barriers such as the tumor microenvironment and cellular membranes.

### 3. Combination Therapy

- **Multi-Drug Delivery:** Nanosponges can be loaded with multiple therapeutic agents, such as chemotherapeutic drugs and targeted antibodies, allowing for combination therapies that may be more effective against cancer.

### 4. Immunotherapy Applications

- **Adjuvant Delivery:** Nanosponges can be used to deliver immune checkpoint inhibitors or other immunotherapy agents directly to the tumor site, enhancing the immune response against cancer cells.



- **Antigen Delivery:** They can also be utilized to deliver cancer-specific antigens to stimulate a targeted immune response.

## 5. Personalized Medicine

- **Customized Treatments:** Nanosponges can be tailored to the specific characteristics of an individual's tumor, such as genetic mutations or receptor profiles, leading to more personalized and effective treatments.

## Challenges and Considerations

### 1. Complex Manufacturing and Costs

- **Development Challenges:** The synthesis and scaling up of nanosponges can be complex and costly, which may affect their widespread availability and affordability.

### 2. Biocompatibility and Safety

- **Toxicity Risks:** Ensuring that nanosponges are biocompatible and do not cause adverse reactions in the body is crucial for their safe use in drug delivery and cancer therapy.

### 3. Regulatory Approval

- **Approval Process:** Navigating the regulatory landscape for new nanosponges-based therapies can be challenging and time-consuming.

### 4. Long-Term Effects

- **Monitoring:** Long-term safety and efficacy must be carefully monitored to identify any delayed adverse effects or issues related to nanosponges' persistence in the body.

## CONCLUSION:

• **Enhanced Targeting and Controlled Release:** Nanosponges provide the ability to deliver drugs with high precision to targeted tissues or cells, minimizing side effects and improving therapeutic outcomes. Their controlled and sustained release capabilities ensure that drugs are delivered over extended periods, potentially reducing the frequency of dosing.

• **Improved Drug Solubility and Stability:** By encapsulating drugs, nanosponges can enhance the solubility of poorly water-soluble drugs and protect them from degradation, thus improving bioavailability and efficacy.

• **Applications in Cancer Therapy:** Nanosponges offer significant potential for advancing cancer treatment through targeted delivery of chemotherapy and immunotherapy agents, combination therapies, and personalized medicine. This approach can lead to more effective treatments with reduced systemic toxicity and enhanced tumor penetration.

• **Challenges and Considerations:** Despite their advantages, nanosponges face several challenges, including complex manufacturing processes, high costs, biocompatibility concerns, and regulatory hurdles. Addressing these issues is crucial for the successful integration of nanosponges into clinical practice.

• **Future Directions:** Ongoing research is essential to optimize nanosponges' design, improve their safety profile, and overcome existing limitations. Advances in nanotechnology, material science, and drug formulation will continue to drive innovation in this field, potentially leading to more effective and accessible treatments for a variety of medical conditions.

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