# Nanogels as an advanced drug delivery system

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***Abstract*—Nanogels have really caught people's attention lately as a smart, flexible way to deliver drugs. Thanks to their tiny, sponge-like structure, they can soak up a lot of water or biological fluids and still hold their shape. That's a big deal because it lets nanogels carry all kinds of therapies small-molecule drugs, proteins, peptides, even genes and vaccines. Unlike older drug delivery tricks, nanogels bring a lot to the table: they keep drugs stable, pack in a lot of medicine, release it in a controlled way, and can even zero in on specific tissues or cells. You can tweak all sorts of things about nanogels their size, charge, porosity, how much they swell to suit whatever the treatment calls for. And it gets better: scientists have figured out how to make nanogels that respond to things like pH, temperature, enzymes, or redox changes. That means you can trigger drug release exactly when and where you want it. This is a game-changer for tough diseases like cancer, inflammatory problems, or neurological issues, where you need to hit the right spot without causing a bunch of side effects elsewhere. In this review, you'll get a full look at nanogels as a drug delivery system what they are, what they're made of, how they're classified, how people make them, how they load up drugs, and how the drugs get released. We'll also dig into the latest applications, the benefits and drawbacks, what regulators are saying, and where the field is heading. Bottom line: nanogels are shaping up to be a powerful tool that could make treatments work better and actually help patients more in the future of medicine.**

***Index Terms*—Advanced drug delivery system, Polymeric nanocarriers, Stimuli-responsive nanogels, Controlled drug release, Targeted drug delivery, Hydrogel nanoparticles, pharmaceutical nanotechnology.**

## I. INTRODUCTION

Getting a drug to the right spot in the body really decides whether a treatment works or not. People rely on standard drug delivery all the time, but these methods have their share of issues. Sometimes, the body doesn't absorb the drug well, or it doesn't dissolve the way it's supposed to. Maybe it just breaks down too quickly, so you end up needing more frequent doses. Even then, hitting the exact target is tricky, and that opens the door to more side effects especially for those dealing with chronic or complicated illnesses. That's why everyone's searching for better, safer ways to deliver drugs that actually do what they're supposed to do.

Nanotechnology has changed the game in pharma lately. By working at the nanoscale, scientists have built delivery systems with way more control over where drugs travel, when they're released, and how they work inside the body. Out of all these innovations, nanogels are getting a lot of attention. Think of them as a mix: they're as tiny as nanoparticles, but have the soft, squishy structure of a hydrogel. Basically, imagine a flexible 3D web of polymers that can soak up a lot of water or body fluids. Thanks to that, nanogels hold onto different drugs and keep them protected until it's time to let them go.

Nanogels have a couple of big things going for them: they can carry a lot, and the body generally doesn't freak out about them. They work with drugs that love water and drugs that don't, and their small size lets them zip through barriers and reach specific cells or tissues. Scientists can also fine-tune nanogels just change the polymer or adjust the cross-linking to match different ways of giving medicine or to fit the needs of a particular treatment.

There's even more happening now. Researchers are making "smart" nanogels that notice what's going on inside your body like changes in pH, temperature, or enzyme levels and release their drugs right where and when they're needed. This is huge for targeted treatments, like cancer therapy or gene therapy. It means fewer side effects and, hopefully, better results for patients.

This article dives into nanogels as a cutting-edge way to deliver drugs. You'll get the basics: what they are, how they're made, and how drugs actually get loaded and released. We'll look at where nanogels already make a difference, what they do well, where they fall short, and where things are headed next. By digging into fresh research and new ideas, you'll see why nanogels are leading the charge in the future of drug delivery.

## II. ADVANTAGES OF NANOGELS IN DRUG DELIVERY

1. Their three-dimensional polymeric network allows for high drug loading capacity.
2. Drug release that is maintained and controlled, minimizing the need for frequent dosage.
3. Enhanced bioavailability of medications with limited solubility.
4. Less harmful, biocompatible and biodegradable.
5. Better cellular absorption and tissue penetration are made possible by small particle size.
6. Targeted medication administration using both active and passive targeting techniques.
7. Site-specific medication release is made possible by stimuli-responsive behavior.
8. Preserving medications from chemical and enzymatic deterioration.
9. Increased patient compliance as a result of fewer adverse effects and fewer doses.

## III. LIMITAION AND CHALLENGES

1. It involves a complicated manufacturing process that requires precise control over crosslinking and polymer composition.
2. Large-scale manufacturing is challenging, which restricts its commercial and industrial applications.
3. Problems with stability during storage include particle size changes or aggregation.
4. High production costs due to sophisticated methods and specialized materials.
5. Variability from batch to batch affects quality control and reproducibility.
6. Some polymers and crosslinking agents may be hazardous, necessitating a thorough safety assessment.
7. Limited long-term in vivo data make clinical translation difficult.
8. Regulatory obstacles arise because nanogel-based systems must adhere to stringent safety and effectiveness requirements.
9. Unpredictable drug release behavior in complex biological settings.
10. Sterilization difficulties can change the structure or functionality of nanogels.

## IV. SELECTION STEPS OF NANOGELS FOR DRUG DELIVERY

a. Identification of therapeutic objective Select the nanogel based on the disease condition, target site, and desired therapeutic outcome.
b. Evaluation of drug properties Consider drug solubility, molecular weight, stability, charge, and sensitivity to pH or enzymes.
c. Selection of polymer type Choose suitable natural or synthetic polymers based on biocompatibility, biodegradability, and drug compatibility.
d. Choice of cross-linking method Decide between physical or chemical cross-linking depending on stability and release requirements.
e. Determination of particle size range Select appropriate nanogel size for efficient tissue penetration and cellular uptake.
f. Surface charge consideration Optimize surface charge to enhance stability, drug loading, and interaction with biological membranes.
g. Drug loading approach selection Choose physical entrapment, electrostatic interaction, or covalent binding based on drug characteristics.
h. Release profile requirement Design nanogels for immediate, sustained, or stimuli-responsive drug release as needed.
i. Route of administration compatibility Ensure the nanogel system is suitable for oral, parenteral, transdermal, or other routes.
j. Biocompatibility and safety assessment Evaluate toxicity, immunogenicity, and biodegradability before final selection.
k. Stability and storage evaluation Confirm physical and chemical stability under storage conditions.
l. Regulatory and scalability consideration Assess feasibility for large-scale production and compliance with regulatory guidelines.

## V. CHARECTERIZATION OF NANOGELS

Proper characterization of nanogels is an essential step to ensure the consistency, quality, and performance of the final drug delivery system. Nanogels possess several distinctive physicochemical properties that strongly influence their drug loading capacity, release behavior, stability, and biological interaction. Due to their nanoscale dimensions, nanogels exhibit unique optical properties such as light scattering, which results from variations in refractive index between the polymer network and the surrounding medium. The cross-linked structure of nanogels creates internal hydrophobic and hydrophilic domains, enhancing the solubilization of poorly water-soluble drugs. In addition, their small size provides a high surface area-to-volume ratio, which improves drug interaction and delivery efficiency. Therefore, a combination of analytical techniques is required to comprehensively evaluate the size, morphology, surface characteristics, and internal structure of nanogels.

1) Dynamic Light Scattering (DLS)

Dynamic light scattering is one of the most commonly used techniques for determining the particle size and size distribution of nanogels dispersed in liquid media. This method measures fluctuations in light scattering caused by the Brownian motion of nanoparticles and provides the hydrodynamic diameter of nanogels. DLS is also useful for evaluating the effect of cross-linking density and polymer chain length on nanogel size. Furthermore, it helps in assessing the swelling behavior of nanogels in different solvents or physiological conditions. Although DLS provides rapid and reliable size measurements, it may be less sensitive to very small particle populations; therefore, it is often combined with other characterization methods.

2) Scanning Electron Microscopy (SEM)

Scanning electron microscopy is employed to study the surface morphology and shape of nanogels. SEM provides high-resolution images that allow visualization of particle size, surface texture, and structural uniformity. This technique is particularly useful for confirming the spherical nature and surface characteristics of nanogels. The obtained images can be further analyzed using image processing software to determine particle size distribution and surface features accurately. SEM plays a crucial role in understanding the physical appearance and morphological consistency of nanogel formulations.

3) Zeta Potential Analysis

Zeta potential measurement is used to determine the surface charge of nanogels, which is an important indicator of colloidal stability. Nanogels with higher absolute zeta potential values tend to exhibit better stability due to electrostatic repulsion between particles, preventing aggregation. Surface charge also plays a key role in drug loading efficiency and interaction with biological membranes, influencing cellular uptake and biodistribution.

4) Transmission Electron Microscopy (TEM)

Transmission electron microscopy provides detailed information about the internal structure and exact size of nanogels at the nanoscale. Unlike SEM, TEM allows visualization of the inner polymeric network and core–shell structures. This technique helps confirm particle uniformity and provides accurate size measurement, making it valuable for advanced structural analysis.

5) Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy is employed to identify functional groups present in nanogels and to confirm successful cross-linking between polymers. It is also useful for studying drug–polymer interactions by detecting shifts or changes in characteristic absorption peaks. FTIR helps ensure chemical compatibility between the drug and nanogel components.

6) Differential Scanning Calorimetry (DSC)

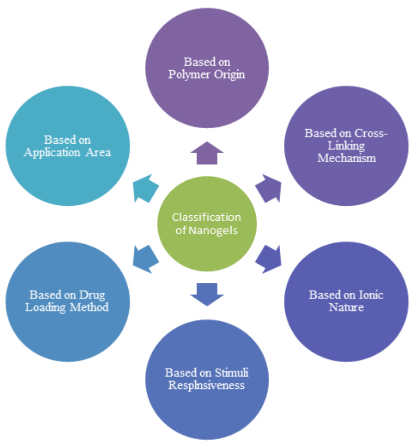
Differential scanning calorimetry is used to evaluate the thermal behavior of nanogels. This technique provides information about phase transitions, melting points, and thermal stability of the formulation. DSC also helps determine whether the drug is present in a crystalline or amorphous state within the nanogel matrix.

7) X-Ray Diffraction (XRD)

X-ray diffraction analysis is carried out to study the crystalline nature of nanogels and loaded drugs. The disappearance or reduction of sharp diffraction peaks indicates conversion of the drug into an amorphous form, which often leads to improved solubility and dissolution characteristics.

8) Drug Loading and Encapsulation Efficiency
Drug loading capacity and encapsulation efficiency are determined to evaluate how effectively the drug is incorporated into the nanogel system. These parameters are crucial for assessing formulation efficiency and therapeutic potential. High encapsulation efficiency ensures minimal drug loss during preparation.

## VI. CLASSIFICATION OF NANOGELS




Nanogels can be classified based on their polymer origin, cross-linking mechanism, ionic nature, and responsiveness to environmental stimuli. This classification helps in selecting suitable nanogel systems for specific drug delivery applications.

1) Based on Polymer Origin
Nanogels are classified as natural, synthetic, or semi-synthetic depending on the source of polymers used. Natural polymer-based nanogels, such as those made from chitosan or alginate, offer good biocompatibility and biodegradability. Synthetic polymer-based nanogels provide better control over size, stability, and drug release. Semi-synthetic nanogels combine the advantages of both natural and synthetic polymers.

2) Based on Cross-Linking Mechanism
Based on the type of cross-linking, nanogels are categorized as physically cross-linked or chemically cross-linked nanogels. Physically cross-linked nanogels are formed through non-covalent interactions such as hydrogen bonding or ionic interactions, making them reversible and sensitive to environmental changes. Chemically cross-linked nanogels contain covalent bonds, offering greater structural stability and sustained drug release.

3) Based on Ionic Nature
According to surface charge, nanogels can be cationic, anionic, or neutral. Cationic nanogels are useful for gene and nucleic acid delivery due to electrostatic interaction with negatively charged biomolecules. Anionic nanogels are generally more stable in biological fluids, while neutral nanogels show reduced non-specific interactions with tissues and proteins.

4) Based on Stimuli Responsiveness
Stimuli-responsive nanogels are designed to respond to specific environmental conditions. These include pH-responsive, temperature-responsive, enzyme-responsive, and redox-responsive nanogels. Such systems enable controlled and site-specific drug release, especially in disease-affected tissues like tumors or inflamed regions.

5) Based on Drug Loading Method
Nanogels can also be classified based on how drugs are incorporated into the system. This includes nanogels loaded through physical entrapment, electrostatic interaction, or covalent attachment. The choice of loading method influences drug stability and release behavior.

6) Based on Application Area
Depending on their intended use, nanogels are classified for cancer therapy, gene delivery, ocular delivery, transdermal delivery, and vaccine delivery. Each category is designed to meet specific therapeutic requirements.

## VII. PREPARATION TECHNIQUES OF NANOGELS

The preparation method of nanogels plays a critical role in determining their size, structure, drug loading efficiency, and release characteristics. Various techniques have been developed to produce nanogels with controlled physicochemical properties suitable for pharmaceutical applications.
The Polymerization Emulsion Method
One of the methods for creating nanogels that is most frequently employed is emulsion polymerization. This technique creates a stable emulsion by dispersing monomers and cross-linking agents in an aqueous phase with surfactants. Chemical initiators are used to start the polymerization process, which produces nanosized gel particles inside the emulsion droplets.

This method generates nanogels with a limited size distribution and provides good control over particle size. Surfactants, however, might necessitate extra purification procedures, which could make the formulation more complicated.

Inverse Miniemulsion Technique

The inverse miniemulsion method is a captivating way to fabricate nanogels, hinging on the interplay of water and oil. To begin, an aqueous solution, containing either a polymer or a monomer, is dispersed within a continuous oil phase. Surfactants come into play here, acting like molecular linkers to help create stable nanodroplets. The real action occurs within these small spaces: cross-linking reactions take place, essentially weaving the material together to fashion nanogels.

Researchers find this method particularly useful for encapsulating hydrophilic substances. It is like a miniature delivery system, capable of carrying drugs, proteins, and even genetic material. The technique also demonstrates significant encapsulation efficiency, which means it can trap a substantial amount of the target substance within the nanogel. Beyond that, it allows for good control over the size of the resultant nanogels, a key aspect in applications like targeted drug delivery.

Yet, the inverse miniemulsion method has its hurdles. Since it involves organic solvents and surfactants, scientists must take care to remove these components before employing the nanogels in biomedical applications. This is a very important step to ensure the final product is biocompatible.

Self-Assembly Method

Self-assembly presents a mild, energy-efficient method, capitalizing on the natural inclination of polymer chains to spontaneously form nanogel structures, which is dictated by specific environmental conditions. This process can be triggered by changes in pH levels, variations in temperature, adjustments to ionic strength, or shifts in solvent polarity. The beauty of this approach lies in the fact that it bypasses the need for harsh chemicals and excessive energy, making it well-suited for sensitive biomolecules like peptides, proteins, and genetic material. Although they're biocompatible, self-assembled nanogels may not be as structurally sound when compared to their chemically cross-linked equivalents.

Cross-Linking Polymerization Method

Nanogels, which are essentially polymer chains intertwined in water, offer an advanced method for delivering drugs. The cross-linking that holds them together can happen in a couple of ways, either with chemicals or through physical processes. When you use chemical cross-linking, you're using agents to form lasting covalent bonds, creating nanogels that are strong and don't easily break down. This approach is great for carefully controlling how the drug is released, which is really important for making sure it works. Physical cross-linking, however, utilizes non-covalent forces such as hydrogen bonding, the attraction between ions, or hydrophobic effects. These nanogels can be reversed, which makes them useful in various situations. It allows for adjustments in how they swell, their physical characteristics, and the pace at which the drug is released, ultimately improving the nanogel's overall effectiveness.

Radiation-Induced Polymerization

Harnessing the might of potent radiation sources such as gamma rays or electron beams, radiation-based polymerization serves to initiate the cross-linking of polymers, thereby negating the requirement for chemical initiators. It's a rather useful method for producing ultra-pure nanogels, and as an added benefit, the process also sterilizes the formulation. The advantages are most apparent in the realm of biomedicine, where rigorous safety standards are, understandably, paramount. However, despite these benefits, the requirement for specialized, costly equipment unfortunately impedes its widespread use in industrial applications.

Precipitation Polymerization

Precipitation polymerization is a smart way to create nanogels, essentially involving the polymerization of monomers in a solvent where the resulting polymer doesn't want to stay – it's insoluble. As the polymer chains get longer, they essentially hit a wall, precipitating out of the solution and forming nanogel particles. A major advantage of this method is that it doesn't require surfactants, which means the nanogels are quite pure and not very toxic a definite plus. What's more, the size of these particles can be adjusted with precision, depending on how the reaction is set up; factors like temperature and the initial concentration of the monomers come into play. But there's a recurring problem when it comes to loading drugs during polymerization; some drugs just don't want to cooperate with this process.

Templet-Assisted Method
The template-assisted approach capitalizes on pre-existing structures, like micelles, nanoparticles, or even porous materials, essentially using them as molds to create nanogels. The process entails polymerizing and cross-linking the nanogel ingredients around the chosen template. After this step is finished, the template is taken out, resulting in nanogels that have specific sizes and shapes. This method is often praised for its exceptional ability to control the physical characteristics and the internal structure of the nanogels. However, it's really important to ensure that the template is completely eliminated, because any left-over material could possibly cause toxicity issues or make the formulation unstable.

## VIII. DRUG LOADING METHODS IN NANOGELS

Drug loading is the process of incorporating a drug into the nanogel system so that it can be delivered safely and effectively to the target site. The method of drug loading mainly depends on the nature of the drug and the polymer used. Proper drug loading helps in improving drug stability and controlled release.

1. Physical Entrapment
In this method, the drug is mixed with the polymer solution during the formation of nanogels. As the nanogel network is formed, the drug gets trapped inside it. This method is very simple and does not involve any chemical reaction. It is suitable for sensitive drugs such as proteins and peptides. However, sometimes the drug may leak out if the nanogel structure is weak.

2. Electrostatic Interaction
This method works on the attraction between opposite charges. Positively charged nanogels can bind with negatively charged drugs, while negatively charged nanogels can hold positively charged drugs. This method is commonly used for loading DNA and gene drugs. Drug release may change when there is a change in pH or salt concentration.

3. Covalent Conjugation
In covalent conjugation, the drug is chemically attached to the polymer of the nanogel. This provides strong binding and prevents early drug release. The drug is released only when the chemical bond breaks inside the body. This method gives controlled drug release but requires careful design because chemical reactions may affect drug activity.

4. Hydrophobic Interaction
Some nanogels contain hydrophobic (water-repelling) parts. Poorly water-soluble drugs can easily attach to these hydrophobic regions. This method improves the solubility and stability of such drugs. It is mainly used for anticancer and lipophilic drugs.

5. Post-Loading (Diffusion Method)
In this method, already prepared nanogels are placed in a drug solution. The drug slowly enters the nanogel network by diffusion. This method is easy and avoids drug damage, but the amount of drug loaded is usually low.

## IX. DRUG RELEASE MECHANISM OF NANOGELS

Drug release mechanism means how the drug is released from nanogels after they enter the body. Nanogels are made in such a way that the drug does not come out suddenly but is released slowly and in a controlled way. This helps in better treatment and reduces side effects.

1. Diffusion Release
In this mechanism, the drug slowly moves out from the nanogel into the surrounding body fluids. The drug comes out because its concentration is higher inside the nanogel and lower outside. This process happens gradually and gives sustained drug release.

2. Swelling Controlled Release
Nanogels can absorb water and swell after coming in contact with body fluids. When the nanogel swells, its structure becomes loose and the drug is released easily. More swelling leads to faster drug release.

3. Degradation Controlled Release
Some nanogels are biodegradable. Inside the body, their polymer structure slowly breaks down due to enzymes or natural processes. As the nanogel breaks, the drug trapped inside is released. This method is useful for long-term drug delivery.

4. pH Sensitive Release
Certain nanogels release drugs depending on the pH of the surrounding area. For example, in acidic conditions like cancer tissues or stomach, the nanogel releases more drug. This helps in targeted drug delivery.

5. Temperature Sensitive Release
In this mechanism, nanogels respond to temperature changes. When the temperature reaches body temperature, the nanogel changes its structure and releases the drug. This method helps in controlled drug delivery.

6. Enzyme Sensitive Release
Some nanogels release drugs only when specific enzymes are present. These enzymes break the nanogel structure and allow the drug to come out. This reduces drug release in healthy tissues.

## X. ROUTE OF ADMINISTRATION

Routes of administration mean the different ways by which nanogels are given to the body to deliver drugs. The choice of route depends on the type of drug, disease condition, and target site. Nanogels are flexible drug carriers and can be administered through many routes.

- Oral
- Parenteral
- Transdermal
- Nasal
- Ocular
- Pulmonary
- Vaginal


1. Oral Route
Nanogels can be given through the mouth in the form of tablets, capsules, or suspensions. They help protect the drug from stomach acid and improve drug absorption. This route is easy and comfortable for patients, but enzymatic degradation may affect some drugs.

2. Parenteral Route
In this route, nanogels are administered through injections such as intravenous, intramuscular, or subcutaneous routes. It provides fast drug action and is useful for targeted drug delivery. However, this route requires skilled handling and sterile conditions.

3. Transdermal Route
Nanogels can be applied on the skin in the form of gels or patches. They help the drug pass through the skin layers and provide prolonged drug release. This route avoids first-pass metabolism and improves patient compliance.

4. Nasal Route
Nanogels administered through the nasal route are absorbed quickly due to high blood supply in the nasal cavity. This route is useful for delivering drugs to the brain and for rapid onset of action. It is non-invasive and convenient.

5. Ocular Route
Nanogels are used in eye formulations like eye drops or eye gels. They increase the residence time of the drug in the eye and improve bioavailability. This route is mainly used for treating eye infections and disorders.

6. Pulmonary Route
In this route, nanogels are inhaled into the lungs. They are useful in treating respiratory diseases such as asthma and lung infections. This route provides direct drug delivery to the lungs with rapid action.

7. Vaginal and Rectal Route
Nanogels can be used for local drug delivery through vaginal or rectal routes. They provide prolonged retention and controlled drug release. This route is useful when oral administration is not suitable.

## XI. APPLICATIONS OF NANOGELS

Nanogels are gel particles at the nanoscale that are used in a variety of pharmaceutical and medical applications. Nanogels offer a wide range of applications in drug delivery and therapy due to their small size, high water content, and controlled drug release capabilities.

1. Targeted Administration of Drugs

Drugs are administered directly to the location of illness using nanogels. They limit adverse effects and lessen drug loss in healthy tissues. This application is highly helpful for treating chronic illnesses and cancer.

2. Cancer Treatment

Anticancer medications are frequently administered via nanogels. They increase the effectiveness of treatment by releasing the medication gradually at the tumor locations. This lessens the toxicity to healthy cells.

3. Delivery of Genes and DNA Genes

DNA, and RNA are delivered into cells via nanogels. They aid in gene therapy and shield genetic material from deterioration. In the treatment of genetic illnesses, this application is crucial.

4. Delivery of Proteins and Peptides

Proteins and peptides can be delivered by nanogels because they shield these medications from enzymatic breakdown. They enhance stability and regulate the body's release of drugs.

5. Drug Delivery Through the Skin

Skin formulations like gels and patches contain nanogels. They facilitate the sustained release of medications and aid in their passage through the skin. By avoiding injections, this application enhances patient comfort.

6. Ocular Medication Administration

Nanogels have changed the way we treat eye diseases and infections. Unlike regular eye drops, they keep medication in the eye longer and help your body absorb more of it.

7. Vaccine Delivery

Nanogels also step in as carriers for vaccines. They protect the antigens and make your immune response stronger. That means vaccines work better and last longer.

8. Antimicrobial Treatment

When it comes to fighting infections, nanogels deliver antibiotics and antifungals more effectively. They control how the medication is released, boost its power against germs, and help cut down on drug resistance.

9. Healing Wounds

Nanogels make wound care a lot easier. They carry healing agents straight to the spot, keep things moist, and that really speeds up the healing process. Plus, they help fight off infections.

10. Uses in Cosmetics and Dermatology

Nanogels show up all over the place in cosmetics-think lotions, creams, that sort of thing. They hold onto moisture and let active ingredients out bit by bit, so your skin ends up feeling softer and looking healthier.

## XII. NANOGELS IN TAGATED DRUG DELIVERY

Nanogels play an important role in targeted drug delivery because they can carry medicines directly to the affected area of the body. Targeted drug delivery means the drug works mainly at the disease site instead of spreading throughout the body. This helps in improving treatment and reducing unwanted side effects Because nanogels are very small in size, they can easily move through blood vessels and reach specific tissues. They have a soft and flexible structure, which allows them to pass through narrow spaces in the body. Once they reach the target area, nanogels slowly release the drug in a controlled manner.

Nanogels can be designed to respond to special conditions present at diseased sites, such as low pH, higher temperature, or specific enzymes. For example, in cancer tissues where the environment is more acidic, nanogels release more drug only at that location. This makes the treatment more effective and safer.

In addition, nanogels can be attached with special molecules like antibodies or ligands. These molecules help nanogels recognize diseased cells and bind to them. Because of this, the drug is delivered more accurately to the target cells and less drug is wasted.

Overall, nanogels improve drug stability, enhance targeting efficiency, and provide controlled drug release. Due to these advantages, nanogels are considered one of the most promising systems for targeted drug delivery.

## XIII. RECENT ADVANCES AND RESEARCH TRENDS

In recent years, nanogels have gained a lot of attention in pharmaceutical research due to their improved performance in drug delivery. Scientists are continuously working on developing advanced nanogels that are safer, more effective, and more specific to disease sites.

One major recent advancement is the development of stimuli-responsive nanogels. These nanogels are designed to release drugs only when they encounter specific conditions such as changes in pH, temperature, enzymes, or redox environment. This approach is especially useful in cancer therapy, where drug release can be triggered only inside tumor tissues, reducing damage to normal cells.

Another important research trend is the use of ligand-targeted nanogels. In this approach, nanogels are modified with antibodies, peptides, or receptor-specific molecules. These ligands help nanogels recognize and bind to specific cells, increasing drug accuracy and improving treatment outcomes. This strategy is widely explored in cancer, gene therapy, and brain targeting.

Recent studies also focus on biodegradable and biocompatible nanogels made from natural polymers such as chitosan, alginate, and gelatin. These nanogels are safer for long-term use because they break down naturally inside the body without causing toxicity.

Another growing area of research is the use of nanogels in gene and RNA delivery. Nanogels are being explored as carriers for siRNA, mRNA, and DNA because they protect genetic material from degradation and improve cellular uptake. This has opened new possibilities in gene therapy and personalized medicine.

Researchers are also working on multi-functional nanogels, which can carry more than one drug or combine drug delivery with imaging agents. These nanogels help in both treatment and diagnosis, a concept known as theragnostic.

Overall, recent advances show that nanogels are moving from basic research towards clinical applications. With ongoing research, nanogels are expected to play a major role in future drug delivery systems.

## XIV. FUTURE PERSPECTIVE OF NANOGELS

Nanogels have a bright future in the field of drug delivery because of their unique properties such as small size, high drug loading, and controlled release. With continuous research and technological development, nanogels are expected to become an important part of advanced pharmaceutical treatments.

In the future, nanogels are likely to be more widely used in personalized medicine. Drugs can be loaded into nanogels according to the specific needs of individual patients, which will improve treatment outcomes and reduce side effects. This approach will be especially useful in cancer therapy and chronic diseases.

Another promising future direction is the development of smart nanogels that can respond more precisely to body conditions such as pH, enzymes, temperature, or specific biomarkers. These nanogels will release drugs only at the disease site, making treatment safer and more effective.

Nanogels are also expected to play a major role in gene therapy and RNA-based treatments. With growing interest in mRNA and gene medicines, nanogels can act as safe carriers to protect and deliver genetic material into cells

In addition, future research will focus on improving the biocompatibility and biodegradability of nanogels using natural and eco-friendly polymers. This will reduce toxicity concerns and make nanogels suitable for long-term use.

Nanogels may also be used more in theranostic applications, where diagnosis and treatment are combined in a single system. This will help doctors monitor treatment progress along with drug delivery.

Overall, with advancements in nanotechnology and biomedical research, nanogels have strong potential to become an effective and reliable drug delivery system in future healthcare.

## XV. CONCLUSION

Nanogels have emerged as an important and promising drug delivery system in modern pharmaceutical research. Their small size, high water content, and flexible structure allow them to carry and release drugs in a controlled manner. Compared to conventional drug delivery systems, nanogels improve drug stability, enhance bioavailability, and reduce side effects.The ability of nanogels to respond to specific conditions such as pH, temperature, and enzymes makes them suitable for targeted drug delivery. They are especially useful in the treatment of cancer, genetic disorders, and chronic diseases. In addition, nanogels can be prepared using biocompatible and biodegradable polymers, which increases their safety for clinical use.

Although some challenges related to large-scale production and long-term safety still exist, continuous research and technological advancements are helping to overcome these limitations. Overall, nanogels represent a versatile and advanced platform with great potential to improve future drug delivery and patient care.

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