IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, October 2024

Synthesis and Characterization of Metal-Based Nanocomposites for Multifunctional Biotechnological Applications

Mritunjay Mandal[1] and Dr. Nagendra Pratap Mishra[2]
Research Scholar, Department of Chemistry[1]
Research Guide, Department of Chemistry[2]
Sunrise University, Alwar, Rajasthan, India

Abstract*: The synthesis, characterisation, and many biological uses of metal complexes and nanocomposites made from a wide range of biopolymeric ligands are thoroughly examined in this review study. Because of their biocompatibility, biodegradability, and functional diversity, these ligands—which include chitosan, 2-hydroxybenzaldehyde, and 4-aminopyridine imine, among others—have demonstrated extraordinary promise. In addition to highlighting sophisticated characterization methods including spectroscopy, microscopy, thermal analysis, and X-ray diffraction, the study explores a variety of synthetic procedures, including conventional and green synthesis approaches. The study discusses the wide range of biological properties that these compounds display, including antibacterial, antioxidant, anticancer, enzyme inhibition, and drug delivery applications. This review attempts to give researchers in medicinal chemistry, materials science, biotechnology, and related disciplines useful insights by summarizing recent work and highlighting important issues and future prospects.*

Keywords: Metal Complexes, Nanocomposites, Synthesis, Characterization, BiologicalApplication

I. INTRODUCTION

With a broad range of applications that connect chemistry, biology, and engineering, the domains of metal complexes and nanocomposites represent significant breakthroughs in materials research. Because of their special structural, electrical, and catalytic qualities, the synthesis and research of these materials have transformed a number of industrial and biological uses. A core metal atom or ion is joined to surrounding molecules or anions, referred to as ligands, to form metal complexes. These complexes are essential to many industrial and biological activities. They are essential, for example, in medical chemistry, where they are used as medications or diagnostic tools, and in catalysis, where they promote chemical reactions in mild environments. Metals may adopt a variety of coordination environments and oxidation states, which allows for the fine-tuning of their physical and chemical characteristics and contributes to their flexibility. Contrarily, nanocomposites are substances that combine nanoscale elements into a matrix of several materials, frequently producing synergistic qualities not present in the constituent parts. These materials' improved mechanical, thermal, electrical, and optical qualities have drawn a lot of interest. By using the special qualities of nanoparticles and their high surface area-to-volume ratio, nanocomposites are used in biomedical applications for antibacterial agents, medication delivery, and imaging. By combining the benefits of both kinds of materials, metal complexes may be added to nanocomposites to further enhance their functionality. Innovations in a number of industries, including as biomedicine, energy storage, and environmental remediation, may result from this collaboration.

Natural polymer-based biopolymeric ligands have attracted attention due to their biocompatibility, biodegradability, and capacity to combine with metals to build intricate structures. Chitosan, alginate, and cellulose are examples of common biopolymers that provide many functional groups for binding metal ions. Utilizing biopolymeric ligands in metal complexes and nanocomposites has several benefits. Biopolymers are often non-toxic and well-tolerated by living things, which makes them appropriate for medicinal applications including tissue engineering and medication delivery. By decomposing biologically, these materials can lessen their negative effects on the environment and get rid of the

IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.53

Volume 4, Issue 1, October 2024

long-term persistence problems that synthetic polymers have. A variety of functional groups found in biopolymers enable complexation with metal ions, enabling the creation of materials with particular characteristics. Biopolymers, which are made from renewable resources, offer a sustainable substitute for materials derived from petroleum. The biocompatibility and usefulness of metal complexes and nanocomposites can be improved by adding biopolymeric ligands, creating new opportunities for drug delivery, biosensing, and environmental sustainability applications.

This study aims to give a thorough overview of metal complexes and nanocomposites' production, characterization, and biological applications. This includes a range of synthesis techniques for metal complexes and nanocomposites, emphasizing both conventional and contemporary methods. Important synthesis techniques include of: These methods create metal complexes and nanocomposites with distinct morphologies and crystal structures by applying high temperatures and pressures in a solvent media. This process produces high-quality goods while lowering reaction times and energy usage by using microwave radiation to cause fast heating. Green synthesis techniques, which prioritize environmental sustainability, minimize hazardous byproducts by producing metal complexes and nanocomposites using natural reagents and safe solvents. The benefits and drawbacks of each approach will be examined, offering guidance on how to choose the best methods for certain uses. Understanding the structure, characteristics, and possible uses of metal complexes and nanocomposites requires characterization. This study will examine a number of characterisation methods, including as nuclear magnetic resonance (NMR) spectroscopy and X-ray diffraction (XRD), which offer insights into the molecular environment and crystalline structure of the produced materials. The morphology and particle size distribution of the material may be seen in great detail using transmission electron microscopy (TEM) and scanning electron microscopy (SEM). The optical characteristics are investigated using ultraviolet-visible (UV-Vis) and photoluminescence (PL) spectroscopy, while the electronic characteristics and its uses in energy storage and sensing are revealed by electrochemical analysis. To evaluate the materials' thermal stability and decomposition behavior, methods such as differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) are used. The review will focus on the diverse biological uses of metal complexes and nanocomposites, including investigating the ways in which these substances work as antimicrobials and how effective they are against different types of infections. talking about how metal complexes and nanocomposites are used in cancer treatment, with an emphasis on how they can stop tumor development and cause cell death. assessing the potential of nanocomposites as vehicles for controlled release and targeted drug administration, improving the effectiveness and lowering the adverse effects of medicinal medicines. investigating the use of these materials in medical imaging for better diagnostic accuracy, including fluorescence and magnetic resonance imaging (MRI). examining the construction and operation of biosensors that use metal complexes for environmental monitoring and disease detection.

Synthesis of Metal Complexes and Nanocomposites

The study of the structures and characteristics of metal complexes created by the interaction of metal ions and ligands is known as coordination chemistry (Psomas, 2020). Coordinate covalent bonds hold a center metal atom or ion to neighboring molecules or ions, known as ligands, in a metal complex. Usually Lewis bases, ligands give the metal center, which functions as a Lewis acid, two electrons. The coordination number, which usually falls between 2 and 12 but is most frequently 4 or 6, is the number of coordinate bonds that are created between the metal and the ligands. Numerous variables affect the type of metal-ligand bond seen in coordination complexes, including The shape and bonding characteristics are influenced by the quantity of accessible d-orbitals and their electron occupancy. The coordination number and shape are influenced by the size and spatial arrangement of the ligands. According to this idea, the ligand's electronic field affects the metal ion's d-orbitals, changing the complex's color, magnetism, and reactivity. The design and creation of complexes with desired features for a variety of applications is guided by the fundamental concepts of coordination chemistry, which are essential to comprehending the synthesis, stability, and reactivity of metal complexes.

There are several ways to synthesize metal complexes, and each has unique benefits and is designed for a certain kind of complex. Metal salts and ligands are dissolved in a solvent in a sealed vessel at high temperatures and pressures using the solvothermal and hydrothermal processes. Through regulated crystal growth and nucleation processes, these techniques encourage the creation of metal complexes, frequently producing extremely crystalline products. Due of the accelerated reaction kinetics caused by the high temperature and pressure, special complex structures that are

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, October 2024

challenging to produce under normal circumstances are formed. In contrast to traditional heating techniques, microwave-assisted synthesis uses microwave radiation to quickly and evenly heat the reaction mixture, greatly cutting down on reaction times. Because it increases reaction speeds and yields high-purity products with regulated particle sizes and morphologies, this method is very useful for creating metal complexes. In addition to being energy-efficient, microwave-assisted synthesis is simple to scale up for commercial use. Green synthesis techniques use renewable resources, eco-friendly solvents, and waste reduction to reduce the negative effects of chemical processes on the environment. Green synthesis techniques for metal complexes frequently use moderate reaction conditions, biodegradable ligands, and water or bio-based solvents. The necessity to create ecologically friendly processes and the increased focus on sustainable chemistry are driving the appeal of these methods.

Metal salts and ligands react in an appropriate solvent under ambient or reflux conditions in conventional synthesis procedures for metal complexes. Because of their ease of use and adaptability, these techniques are popular in labs. Temperature, reaction duration, and solvent selection are important factors that affect the yield and purity of the final complexes. The production of metal complexes heavily relies on biopolymeric ligands, which are made from natural polymers. Their distinct benefits, which include biocompatibility, biodegradability, and functional flexibility, make them appealing for a range of uses in environmental remediation, catalysis, and medicine.

The creation and stability of metal complexes depend heavily on the choice of biopolymeric ligands. The complexation process is affected by a number of variables, including the polymer's molecular weight and structure, the functional groups it contains, and how well they attach to the metal ion. Chitosan, alginate, and gelatin are examples of common biopolymeric ligands that have distinct metal coordination functions. The intended uses and characteristics of the final complex determine which metal is used for complexation. Because of their propensity to form stable complexes with biopolymeric ligands and their varying oxidation states, transition metals including copper, nickel, and zinc are often employed. The coordination geometry and stability of the complexes are also influenced by the size and electrical configuration of the metal.

Because its amino and hydroxyl functional groups may interact with metal ions, chitosan, a biopolymer made from chitin, is frequently utilized as a ligand. It is utilized in waste treatment, medicine delivery, and biosensors, and it forms stable complexes with a range of metals. With its oxygen atoms, this molecule, which has both hydroxyl and aldehyde groups, may function as a chelating ligand and create stable metal complexes. Schiff base ligands, which are well-known for their capacity to create stable and adaptable metal complexes, are frequently synthesized using it. Through the nitrogen atom, the imine group in 4-aminopyridine imine offers a location for metal coordination. The stability and reactivity of the resultant complexes are improved by this ligand's capacity to form stable chelate rings with metal ions. When creating metal complexes with biopolymeric ligands, the reaction conditions include variables like temperature, pH, and reaction duration. Effective metal-ligand binding is facilitated by optimal pH values, which guarantee the protonation or deprotonation of functional groups. The complexation process's kinetics and yield are influenced by temperature and reaction duration; greater temperatures frequently cause the reaction to speed up.

Materials called nanocomposites are made of a matrix in which nanoparticles have been inserted to improve or add new characteristics. Because of the nanoscale interactions between the matrix and the nanoparticles, these materials have special mechanical, thermal, electrical, and catalytic capabilities. A family of nanocomposites known as metal-organic frameworks is made up of metal ions or clusters that have been coordinated to organic ligands to create crystalline, porous structures. Because of its large surface area, adjustable porosity, and wide range of chemical functions, MOFs are well-suited for use in drug administration, gas storage, separation, and catalysis. Nanocomposites having a core substance covered with a shell of a separate material are known as core-shell structures. characteristics from the core and the shell are combined in this form to give better optical or magnetic characteristics, controlled release of active agents, and increased stability.

Nanocomposites are created using a variety of methods, each of which provides control over the distribution, size, and form of the nanoparticles inside the matrix. Co-precipitation creates a composite material by precipitating matrix and nanoparticle precursors from a solution at the same time. Large-scale production is made possible by this straightforward and economical process. The final nanocomposites frequently show a homogeneous dispersion of nanoparticles in the matrix. A solution (sol) is transformed into a solid gel phase during the sol-gel process. Usually employed as precursors, metal alkoxides or metal salts go through condensation and hydrolysis processes to create a network structure. This process yields materials with excellent uniformity and purity by precisely controlling the nanocomposite's structure and content. The process of chemical vapor deposition (CVD) creates a thin layer of the target material by breaking down volatile precursors on the surface of a substrate. High-quality nanocomposite films with regulated thickness and composition are frequently produced using CVD. It is very helpful for covering nanoparticles with functional or protective layers and creating core-shell nanocomposites. Nanocomposites can be functionalized by altering their surface characteristics to improve performance and customize them for particular uses. Grafting functional groups or molecules onto the surface of nanoparticles is one method of surface modification that can increase the particles' compatibility with the matrix and improve characteristics including stability, reactivity, and dispersibility. For uses like medication delivery, where the surface characteristics of the nanoparticles affect how they interact with biological systems, surface modification is essential. To change the characteristics of the nanocomposite, doping entails adding trace quantities of foreign components. For instance, doping semiconductor nanoparticles with rare-earth elements can improve their optical and electrical characteristics, whereas doping metal oxide nanoparticles with transition metals can increase their catalytic activity. Doping is a flexible technique for adjusting nanocomposites' performance for particular uses. A variety of methods and strategies are used in the synthesis of metal complexes and nanocomposites in order to get the required characteristics and functions. The design and construction of metal complexes are guided by coordination chemistry principles, and the creation of sophisticated nanocomposites with a wide range of applications is made possible by several synthesis techniques and functionalization strategies.

Characterization Techniques

In materials science and chemistry, characterization techniques are vital instruments that offer vital information on the characteristics and actions of materials. These methods fall into the following general categories: thermal analysis, optical and electrical characteristics, morphological, and structural. Different techniques that highlight distinct facets of the nature and functionality of the material are included in each category.

Materials' atomic and molecular structures are ascertained by structural characterisation procedures. They include details on angles, bond lengths, atom configuration, and other structural elements. A wide range of techniques known as spectroscopic methods use electromagnetic radiation's interaction with materials to examine its characteristics. Among these techniques is one for figuring out a material's crystallographic structure. A substance is exposed to X-rays, and the atomic structure is ascertained by analyzing the diffraction pattern. XRD is very helpful for determining lattice parameters and detecting crystalline phases. By studying how nuclei behave in a magnetic field, NMR spectroscopy may be used to identify the structure of both organic and certain inorganic molecules. It offers comprehensive details on the electronic surroundings of particular nuclei, which may be utilized to infer molecular structure. FTIR spectroscopy measures the amount of infrared light absorbed by a substance in order to detect functional groups and investigate molecular interactions. The resultant spectrum is the molecular fingerprint of the item.

An effective method for figuring out a crystal's atomic and molecular structure is XRD. X-rays are diffracted in certain directions when they strike a crystal. A crystallographer may create a three-dimensional image of the electron density inside the crystal by calculating the angles and intensities of these diffracted beams. The mean locations of the atoms in the crystal, their chemical bonds, the crystallographic disorder, and other details may all be ascertained from this electron density.

NMR spectroscopy makes use of some atomic nuclei's magnetic characteristics. Certain atoms' nuclei resonate at distinctive frequencies when exposed to a magnetic field. The nuclei can be disturbed by administering a radiofrequency pulse, and the signal that results can be analyzed to reveal details about the nucleus's immediate surroundings. This method works very well for figuring out the structures of proteins, nucleic acids, and chemical molecules in solution.

The ability of a substance to absorb light at various wavelengths in the infrared portion of the spectrum is measured using FTIR spectroscopy. Because each type of chemical bond absorbs infrared light at a certain wavelength, the resultant spectrum can reveal information about the types of bonds present in the material. FTIR is often used to examine molecular interactions and chemical processes, as well as to identify organic molecules and functional groups.

At the microscopic and nanoscopic levels, morphological characterisation techniques reveal details about the size, shape, distribution, and surface structure of materials. SEM creates pictures of a sample by using a concentrated

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, October 2024

electron beam. The sample's atoms and electrons interact to produce a variety of signals that may be picked up and transformed into a picture. With a depth of field that allows for three-dimensional viewing, SEM offers fine-grained pictures of the sample surface. It is frequently employed to investigate the composition and surface morphology of materials. In TEM, an electron beam is sent through an extremely thin material. As the electrons go through the sample, they interact with it to create a picture. At extremely high resolutions, down to the atomic level, TEM offers details on the sample's internal structure. It is an essential tool for researching a material's fine structure and composition. AFM scans a sample's surface using a cantilever with a sharp tip. A topographic map of the sample surface is created by measuring the cantilever's deflection when the tip contacts with it. AFM is used to research mechanical characteristics, morphology, and surface roughness. It can provide three-dimensional pictures of surfaces at nanoscale resolution.

Materials' electrical characteristics and interactions with light are investigated using optical and electronic characterisation methods. UV-Vis spectroscopy quantifies how much visible and ultraviolet light a substance absorbs. Numerous compounds may be identified and quantified using the information about the material's electronic transitions that the absorption spectrum offers. In chemistry, UV-Vis spectroscopy is frequently used to investigate chemical processes and quantify concentrations. When a substance absorbs photons, it emits light, which is measured using PL spectroscopy. Information about the material's flaws and electronic structure may be found in the light that is released. Organic light-emitting diodes, semiconductors, and other optoelectronic materials are frequently studied using PL. Examining how a material's electrical characteristics change in response to an applied voltage or current is known as electrochemical analysis. Redox processes, conductivity, and other electrochemical characteristics are studied using methods including chronoamperometry, cyclic voltammetry, and impedance spectroscopy. These methods are essential for comprehending corrosion processes, fuel cells, and battery materials.

Techniques for thermal analysis quantify how a material's chemical and physical characteristics vary with temperature. As a sample is heated or cooled, TGA determines its mass. Mass changes can reveal details on oxidation, breakdown, and other heat processes. The composition and thermal stability of materials are investigated using TGA. When a sample is heated or cooled, DSC detects the amount of heat that enters or exits the sample. This method yields data on reaction kinetics, specific heat capacity, and phase transitions including melting and crystallization. The study of polymers, medications, and other materials makes extensive use of DSC.

In materials science and chemistry, characterization techniques are crucial instruments that offer crucial details regarding the morphology, structure, optical and electrical characteristics, and thermal behavior of materials. By using these methods, scientists may create new materials with specific qualities for a range of uses and comprehend the basic characteristics of existing materials. Characterization techniques are always changing as a result of technological advancements, providing even more accuracy and understanding of the materials that influence our environment.

Biological Applications of Metal Complexes and Nanocomposites

For a number of biological uses, such as antibacterial activity, anticancer qualities, and antioxidant potential, metal complexes and nanocomposites have shown great promise. These substances have notable effectiveness against a variety of infections and illnesses and provide distinctive modes of action. This examines the biological uses of metal complexes and nanocomposites, emphasizing their examples, methods, and their medical and disease-prevention ramifications.

The growing number of bacteria that are resistant to antibiotics has drawn a lot of interest to the antimicrobial properties of metal complexes and nanocomposites. These substances show effectiveness against a range of diseases and provide different modes of action. Metal ions can interact with bacterial cell membranes, rupturing their integrity and causing the contents of the cell to spill out. This is one of the ways that metal complexes and nanocomposites demonstrate antibacterial activity. ROS may be produced by metal complexes and nanocomposites, which can harm bacterial cells oxidatively. Key enzymes involved in bacterial metabolism can be inhibited by metal complexes, which can stop growth or cause cell death.

The antibacterial qualities of metal complexes and nanocomposites have been shown in several investigations. For instance, silver nanoparticles are efficient against viruses, fungi, and both Gram-positive and Gram-negative bacteria due to their broad-spectrum antibacterial action. By rupturing cell membranes and interfering with enzyme function, copper complexes have been demonstrated to stop the development of bacteria. Multidrug-resistant bacteria are among

IJARSCT ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53 Volume 4, Issue 1, October 2024

the pathogens that zinc oxide nanoparticles incorporated in polymer matrix have shown antibacterial effectiveness against.

Potential uses for the antibacterial qualities of metal complexes and nanocomposites in healthcare and sanitation include the incorporation of these materials into wound dressings to aid in wound healing and infection prevention. To lower the risk of illnesses linked to healthcare, antimicrobial coatings made of metal complexes or nanocomposites can be applied to surfaces, equipment, and medical devices. Water can be disinfected and purified using metal-based antimicrobial treatments, especially in places where access to clean water is scarce. Numerous pathogens, including as bacteria, fungi, viruses, and parasites, have been shown to be effectively combatted by metal complexes and nanocomposites. They are potential options for fighting infectious illnesses and tackling antibiotic resistance because of their broad-spectrum action.

Significant anticancer effects are demonstrated by metal complexes and nanocomposites, which provide new methods of growth inhibition and cell death. Through a number of methods, metal complexes and nanocomposites can cause cancer cells to undergo apoptosis, including When metal complexes interact with DNA, they can cause strand breakage and impede transcription and DNA replication. Metal complexes have the ability to interfere with mitochondrial activity, which can trigger cell death pathways and release apoptotic proteins. Growth inhibition and cell death can result from metal complexes' modulation of signaling pathways involved in cell survival, proliferation, and apoptosis.

Metal complexes and nanocomposites have been shown in several preclinical and clinical investigations to be effective anticancer agents. For instance, one of the most popular anticancer medications is cisplatin, a platinum-based compound that has shown promise against a range of solid tumors, such as testicular, ovarian, and lung malignancies. With increased tumor accumulation and less systemic toxicity, gold nanoparticles functionalized with anticancer medications or targeted ligands have demonstrated promise in the treatment of cancer. Metal-based drug delivery systems can deliver anticancer medications precisely to tumor tissues, decreasing off-target effects and enhancing therapeutic results. Metal complexes and nanocomposites also offer promise for a variety of therapeutic uses in the treatment of cancer. To increase effectiveness and get past resistance, metal complexes can be used in conjunction with other anticancer medications or treatments including immunotherapy, radiation therapy, or chemotherapy. Personalized treatment plans and real-time treatment response monitoring are provided by metal-based theranostic compounds, which may be used for both imaging and therapy.

Studies conducted both in vitro and in vivo have shown that metal complexes and nanocomposites are safe and effective in treating cancer. These investigations aid in the development of new anticancer treatments by offering insightful information on their pharmacokinetics, biodistribution, and therapeutic potential.

Through a variety of methods, metal complexes and nanocomposites have antioxidant capability, with potential health and disease preventive implications. Through a number of methods, metal complexes and nanocomposites can scavenge free radicals and prevent oxidative stress, such as: By giving reactive oxygen species electrons, metal complexes can counteract their negative effects and shield biomolecules from oxidative damage. Transition metal ions can be chelated by metal complexes, which stops them from participating in Fenton-like processes and producing ROS. Metal complexes can strengthen cellular antioxidant defenses by upregulating the production of antioxidant enzymes like catalase and superoxide dismutase (SOD).

Numerous metal complexes and nanocomposites have shown both in vitro and in vivo antioxidant properties. Manganese complexes, such manganese porphyrins, for instance, have strong antioxidant qualities and have been studied for the treatment of illnesses linked to oxidative stress, including cardiovascular and neurological conditions. Increased antioxidant activity and stability are demonstrated by graphene oxide nanocomposites functionalized with antioxidant chemicals, such as polyphenols or vitamin E derivatives, which may find use in tissue engineering and medication delivery. The following are some health and disease preventive implications of metal complexes' and nanocomposites' antioxidant potential: Age-related oxidative stress and inflammation can be reduced by antioxidant metal complexes and nanocomposites, which lowers the risk of age-related illnesses including cardiovascular disease, Parkinson's disease, and Alzheimer's disease. Because they scavenge free radicals and lessen oxidative damage to ecosystems and organisms, metal-based antioxidants can be utilized for pollution management and environmental restoration.

Enzyme inhibition is essential for controlling metabolic reactions in living things. With their distinct processes and their therapeutic uses, metal complexes and nanocomposites have become attractive options for enzyme inhibition. Enzymes can be inhibited by metal complexes and nanocomposites by a number of methods, including Enzymatic activity is efficiently blocked by metal complexes, which compete with the substrate for binding to the enzyme's active site. Enzyme conformation is changed and enzymatic activity is decreased when metal complexes attach to an allosteric site on the enzyme. The enzyme and the enzyme-substrate complex are both bound by metal complexes, which lowers the substrate turnover rate.

The enzyme-inhibitory qualities of metal complexes and nanocomposites have been shown in several investigations. Platinum complexes, for instance, have the potential to be anticancer medicines since they have been demonstrated to bind to DNA polymerase enzymes and impede DNA synthesis. Enzyme inhibitor-functionalized gold nanoparticles have been created to selectively block proteolytic enzymes, potentially providing treatment for inflammatory conditions. The potential for treating a number of illnesses, such as cancer, inflammation, and infectious diseases, stems from metal complexes and nanocomposites' capacity to specifically block enzymes. Compared to conventional medications, these materials may provide more potent and less harmful therapeutic alternatives by specifically targeting enzymes implicated in disease processes.

Metal complex and nanocomposites-based drug delivery systems provide special benefits such controlled release, focused distribution, and less adverse effects. Drugs can be encapsulated and delivered to certain bodily targets by designing and functionalizing metal complexes and nanocomposites. Selective binding to sick cells or tissues is made possible by surface alterations with targeted ligands, such as peptides or antibodies. Drug distribution that is targeted and sustained over time is made possible by controlled release mechanisms. Drug release at certain bodily locations can be triggered by engineering metal complexes and nanocomposites to react to different stimuli, such as pH, temperature, or light. The effectiveness of metal-based drug delivery systems in preclinical and clinical settings has been shown in several research. For instance, it has been demonstrated that iron oxide nanoparticles coated with anticancer medications preferentially aggregate in tumor tissues and release medications in response to magnetic hyperthermia, which improves tumor regression and lowers systemic toxicity. To lower the possibility of systemic adverse effects linked to systemic antibiotic therapy, silver nanoparticles encapsulated in hydrogels have been produced for the localized administration of antimicrobial drugs.

With improved contrast, sensitivity, and specificity over conventional imaging agents, metal complexes and nanocomposites are essential components of imaging and diagnostic instruments. Metal complexes, such gadolinium-based contrast agents, are frequently employed in magnetic resonance imaging (MRI) to view particular molecular targets or to improve contrast between various tissues. When compared to free agents, MRI contrast agents in nanocomposites provide better stability, circulation time, and targeting capabilities. Fluorescence imaging makes extensive use of fluorescent metal complexes and nanocomposites to identify and visualize certain biomolecules or cellular processes. For both in vitro and in vivo applications, these materials provide excellent sensitivity, multiplexing capabilities, and real-time imaging capabilities.

Metal complex-based biosensors are useful instruments for disease monitoring and diagnosis because they provide sensitive and selective biological analyte detection. When a particular analyte is present, metal complexes can act as detecting elements in biosensors, sending out a signal. Target molecules can be selectively detected with high sensitivity and specificity when functionalized with recognition components like aptamers or antibodies. Metal complex-based biosensors have been created to detect and track a number of illnesses, such as cancer, infectious infections, and metabolic abnormalities. These biosensors can support early diagnosis and individualized treatment plans in addition to providing quick, point-of-care testing capabilities. From drug transport and enzyme inhibition to imaging and biosensing, metal complexes and nanocomposites have enormous promise for a variety of biological applications. They are useful instruments for furthering biological research and tackling important healthcare issues because of their special qualities and adaptable features. Unlocking the full potential of these materials to enhance human health and well-being requires ongoing study and innovation in this area.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, October 2024

Challenges and Future Perspectives in the Use of Metal Complexes and Nanocomposites

From antibacterial activity to anticancer capabilities, metal complexes and nanocomposites have enormous potential for a variety of biological applications. To reach their maximum potential, a number of obstacles must be overcome. the present difficulties, potential avenues for future study, and moral and environmental issues related to the utilization of metal complexes and nanocomposites in biological applications.

The scalability and repeatability of synthesis techniques are two of the main obstacles to the use of metal complexes and nanocomposites. Many synthesis methods require a lot of work, take a long time, and are challenging to scale up for industrial production. Inconsistencies in the characteristics and functionality of the synthesized materials might also result from differences in raw ingredients and experimental setup. The stability and biocompatibility of metal complexes and nanocomposites provide additional difficulties. Under physiological circumstances, certain metal complexes may not be very stable, which over time can cause deterioration and a loss of function. Additionally, the potential uses of metal ions or nanoparticles in vivo may be limited due to issues of toxicity and biocompatibility that arise when they are introduced into biological systems.

Future studies should concentrate on creating novel synthesis methods for metal complexes and nanocomposites that tackle problems with stability, scalability, and repeatability. Chemical engineering, materials science, and nanotechnology developments can result in the creation of innovative synthesis techniques that are economical, effective, and ecologically benign. Future studies should investigate novel biological uses for metal complexes and nanocomposites in addition to tackling technological issues. Targeted drug delivery, regenerative medicine, and diagnostic imaging are only a few of the uncharted territories, despite the notable advancements in fields like antibacterial activity and anticancer qualities. Researchers can find new ways to enhance human health and well-being by broadening their studies.

When creating metal complexes and nanocomposites, environmental sustainability is a crucial factor. Conventional synthesis techniques frequently use energy-intensive procedures, dangerous chemicals, and solvents, which pollute the environment and deplete resources. Future studies should concentrate on creating greener synthesis methods that use renewable materials, decrease waste production, and use less energy.

It is also important to carefully analyze the ethical implications of using metal complexes and nanocomposites in biological applications. Even while these materials have a lot of potential to advance medical care and diagnosis, safety, privacy, and equality are ethical issues. To guarantee that the advantages of new technologies are shared fairly and that any possible hazards are appropriately controlled, researchers, legislators, and medical experts must collaborate. Although metal complexes and nanocomposites have intriguing prospects for biological applications, a number of obstacles must be overcome before their full promise can be realized. Scientists can open up new creative possibilities and help progress biotechnology and healthcare by tackling problems with stability and biocompatibility, synthesis scalability and reproducibility, and environmental and ethical concerns. The future of metal complexes and nanocomposites in biology is quite promising for enhancing human health and well-being via teamwork and interdisciplinary study.

II. CONCLUSION

Metal complexes and nanocomposites have a wide range of biological applications, and this study highlights their synthesis, characterization methods, and biological uses. In the creation of metal complexes and nanocomposites, synthesis techniques are essential, and scientists are always working to increase their scalability, repeatability, and sustainability. The structural, morphological, and functional characteristics of these materials may be better understood by using characterization methods including spectroscopy, microscopy, and thermal analysis. Numerous biological functions, such as antibacterial, anticancer, antioxidant, drug transport, imaging, and biosensing capabilities, are displayed by metal complexes and nanocomposites. These materials have demonstrated encouraging outcomes in preclinical and clinical trials and provide new modes of action.

Future technology might be greatly impacted by metal complexes and nanocomposites. These resources are essential for tackling some of the most important issues facing the medical field, such as cancer treatment, antibiotic resistance, and diagnostic imaging. Researchers can create novel approaches to enhancing human health and well-being by utilizing the special qualities of metal complexes and nanocomposites. Additionally, the multidisciplinary character of

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, October 2024

this field's study creates fresh chances for cooperation and creativity. We can speed up the discovery and conversion of these technologies into practical uses by bringing together experts with a variety of disciplines, such as chemistry, materials science, biology, and medicine. In biomedical research, metal complexes and nanocomposites are a promising area that might transform healthcare and open the door to new biotechnological developments. The future is full with great opportunities to further our knowledge of biology and improve human health as we continue to investigate and discover the potential of these materials.

REFERENCES

[1]. Adhi, T.P., Aqsha, A., & Indarto, A. (2024). Comparative studies on thermal, microwave- assisted, and ultrasound-promoted preparations. *Green Chemical Synthesis with Microwaves and Ultrasound*, 337-380.

[2]. Ahmad, N., Bukhari, S.N.A., Hussain, M.A., Ejaz, H., Munir, M.U., & Amjad, M.W. (2024). Nanoparticles incorporated hydrogels for delivery of antimicrobial agents: developments and trends. *RSC Advances*, *14*(19), 13535-13564.

[3]. Alshangiti, D.M., El-Damhougy, T.K., Zaher, A., & Madani, M. (2023). Revolutionizing biomedicine: advancements, applications, and prospects of nanocomposite macromolecular carbohydrate-based hydrogel biomaterials: a review. *RSC advances*, *13*(50), 35251-35291.

[4]. Althomali, R.H., Alamry, K.A., Hussein, M.A., & Tay, G.S. (2022). Versatile applications of biopolymer nanocomposites: a review. *ChemistrySelect*, *7*(31), e202200843.

[5]. Begley, M.R., Gianola, D.S., & Ray, T.R. (2019). Bridging functional nanocomposites to robust macroscale devices. *Science*, *364*(6447), p.eaav4299.

[6]. Berestova, T.V., Nosenko, K.N., Lusina, O.V., Kuzina, L.G., Kulish, E.I., & Mustafin, A.G. (2020). Estimating the stability of metal–ligand bonding in carboxyl-containing polymer complexes by IR spectroscopy. *Journal of Structural Chemistry*, *61*, 1876- 1887.

[7]. Carrola, M., Asadi, A., Zhang, H., Papageorgiou, D.G., Bilotti, E., & Koerner, H. (2021). Bestof both worlds: Synergistically derived material properties via additive manufacturing of nanocomposites. *Advanced Functional Materials*, *31*(46), p.2103334.

[8]. Chaouiki, A., Fatimah, S., Chafiq, M., Ryu, J., & Ko, Y.G. (2024). State-of-the-art advancements in metal– organic framework nanoarchitectures for catalytic applications. *Applied Materials Today*, *38*, 102224.

[9]. Chen, S., Tariq, N.H., & Gu, Y. (2024). Recent achievements in organic reactions in bio- based solvents. *Green Solvents in Organic Synthesis*, 107-135.

[10]. Chen, W., & Yu, H.Q. (2021). Advances in the characterization and monitoring of natural organic matter using spectroscopic approaches. *Water Research*, *190*, 116759.

[11]. Daramola, G.O., Adewumi, A., Jacks, B.S., & Ajala, O.A. (2024). Conceptualizing communication efficiency in energy sector project management: the role of digital tools and agile practices. *Engineering Science & Technology Journal*, *5*(4), 1487- 1501.

[12]. Daramola, G.O., Adewumi, A., Jacks, B.S., & Ajala, O.A. (2024). Navigating complexities: a review of communication barriers in multinational energy projects. *International Journal of Applied Research in Social Sciences*, *6*(4), 685-697.

[13]. Daramola, G.O., Jacks, B.S., Ajala, O.A., & Akinoso, A.E. (2024). Enhancing oil and gas exploration efficiency through ai-driven seismic imaging and data analysis. *Engineering Science & Technology Journal*, *5*(4), 1473-1486.

[14]. Daramola, G.O., Jacks, B.S., Ajala, O.A., & Akinoso, A.E. (2024). AI applications in reservoir management: optimizing production and recovery in oil and gas fields. *Computer Science & IT Research Journal*, *5*(4), 972-984.

[15]. Echlin, M.P., Burnett, T.L., Polonsky, A.T., Pollock, T.M., & Withers, P.J. (2020). Serial sectioning in the SEM for three dimensional materials science. *Current Opinion in Solid State and Materials Science*, *24*(2), 100817.

[16]. Fakhar-e-Alam, M., Mahmood, A., Nasir, S., Saadullah, M., Akram, M., & Willander, M. (2020). Gadolinium-doped iron nanostructures decorated with novel drugs for magnetic resonance imaging, photodynamic, and photothermal therapy applications. *Magnetic Nanoheterostructures: Diagnostic, Imaging and Treatment*, 121-159.

[17]. Fasae, K.D., Abolaji, A.O., Faloye, T.R., Odunsi, A.Y., Oyetayo, B.O., Enya, J.I., Rotimi, J.A., Akinyemi, R.O., Whitworth, A.J., & Aschner, M. (2021). Metallobiology and therapeutic chelation of biometals (copper, zinc and iron) in Alzheimer's disease: Limitations, and current and future perspectives. *Journal of Trace Elements in Medicine and Biology*, *67*, 126779.

[18]. Guda, A.A., Guda, S.A., Martini, A., Kravtsova, A.N., Algasov, A., Bugaev, A., Kubrin, S.P., Guda, L.V., Šot, P., van Bokhoven, J.A., & Copéret, C. (2021). Understanding X-ray absorption spectra by means of descriptors and machine learning algorithms. *NPJ Computational Materials*, *7*(1), p.203.

[19]. Iggo, J.A., Jonathan, A., & Luzyanin, K. (2020). *NMR spectroscopy in inorganic chemistry*.

[20]. Oxford University Press.

[21]. Jayakumar, A., Mathew, S., Radoor, S., Kim, J.T., Rhim, J.W., & Siengchin, S. (2023).Recent advances in two-dimensional nanomaterials: Properties, antimicrobial, and drug delivery application of nanocomposites. *Materials Today Chemistry*, *30*, 101492.

[22]. Ji, X., Cheng, Y., Tian, J., Zhang, S., Jing, Y., & Shi, M. (2021). Structural characterization ofpolysaccharide from jujube (Ziziphus jujuba Mill.) fruit. *Chemical and Biological Technologies in Agriculture*, *8*, 1-7.

[23]. Joudeh, N., & Linke, D. (2022). Nanoparticle classification, physicochemical properties,characterization, and applications: a comprehensive review for biologists. *Journal of Nanobiotechnology*, *20*(1), 262.

[24]. Juan, C.A., Pérez de la Lastra, J.M., Plou, F.J., & Pérez-Lebeña, E. (2021). The chemistry of reactive oxygen species (ROS) revisited: outlining their role in biological macromolecules (DNA, lipids and proteins) and induced pathologies. *International Journal of Molecular Sciences*, *22*(9), 4642.

[25]. Kumar, S., Shukla, M.K., Sharma, A.K., Jayaprakash, G.K., Tonk, R.K., Chellappan, D.K., Singh, S.K., Dua, K., Ahmed, F., Bhattacharyya, S., & Kumar, D. (2023). Metal- based nanomaterials and nanocomposites as promising frontier in cancer chemotherapy. *MedComm*, *4*(2), e253.

[26]. Lehnert, N., Kim, E., Dong, H.T., Harland, J.B., Hunt, A.P., Manickas, E.C., Oakley, K.M., Pham, J., Reed, G.C., & Alfaro, V.S. (2021). The biologically relevant coordination chemistry of iron and nitric oxide: electronic structure and reactivity. *Chemical Reviews*, *121*(24), 14682-14905.

[27]. Lino, C., Barrias, S., Chaves, R., Adega, F., Martins-Lopes, P., & Fernandes, J.R. (2022). Biosensors as diagnostic tools in clinical applications. *Biochimica et Biophysica Acta (BBA)-Reviews on Cancer*, *1877*(3), 188726.

[28]. Lou, Z., Zhang, Y., Li, Y., & Xu, L. (2023). Study on microscopic physical and chemical properties of biomass materials by AFM. *Journal of Materials Research and Technology*, *24*, 10005-10026.

[29]. Mahmood, T., Ullah, A., & Ali, R. (2022). Improved nanocomposite materials and their applications. In *Nanocomposite Materials for Biomedical and Energy Storage Applications*. IntechOpen.

[30]. Maruthapandi, M., Saravanan, A., Das, P., Natan, M., Jacobi, G., Banin, E., Luong, J.H., & Gedanken, A. (2020). Antimicrobial activities of Zn-doped CuO microparticles decorated on polydopamine against sensitive and antibiotic-resistant bacteria. *ACS Applied Polymer Materials*, *2*(12), 5878-5888.

[31]. Mehta, V.N., Desai, M.L., Basu, H., Singhal, R.K., & Kailasa, S.K. (2021). Recent developments on fluorescent hybrid nanomaterials for metal ions sensing and bioimaging applications: A review. *Journal of Molecular Liquids*, *333*, 115950.

[32]. Mohanty, P., Mahapatra, R., Padhi, P., Ramana, C.V., & Mishra, D.K. (2020). Ultrasonic cavitation: An approach to synthesize uniformly dispersed metal matrix nanocomposites—A review. *Nano-Structures & Nano-Objects*, *23*, 100475.

[33]. Mondal, P., Anweshan, A., & Purkait, M.K. (2020). Green synthesis and environmentalapplication of iron-based nanomaterials and nanocomposite: a review. *Chemosphere*, *259*, 127509.

[34]. Mutalik, C., Lin, I.H., Krisnawati, D.I., Khaerunnisa, S., Khafid, M., Hsiao, Y.C., & Kuo,

[35]. T.R. (2022). Antibacterial pathways in transition metal-based nanocomposites: a mechanistic overview. *International Journal of Nanomedicine*, *17*, p.6821.

[36]. Ngoepe, M.P., & Clayton, H.S. (2021). Metal complexes as DNA synthesis and/or repair inhibitors: anticancer and antimicrobial agents. *Pharmaceutical Fronts*, *3*(04), e164- e182.

[37]. Oduro, P., Uzougbo, N.S., & Ugwu, M.C. (2024). Navigating legal pathways: Optimizing energy sustainability through compliance, renewable integration, and maritime efficiency. *Engineering Science & Technology Journal, 5*(5), 1732-1751.

[38]. Oduro, P., Uzougbo, N.S., & Ugwu, M.C. (2024). Renewable energy expansion: Legal strategies for overcoming regulatory barriers and promoting innovation. *International Journal of Applied Research in Social Sciences, 6*(5), 927-944.

[39]. Onwuka, O., Obinna, C., Umeogu, I., Balogun, O., Alamina, P., Adesida, A., Kolawale, A., Sokubo, I., Osimobi, J., Uche, J., & Mcpherson, D. (2023, July). Using high fidelity OBN seismic data to unlock conventional near field exploration prospectivity in Nigeria's shallow water offshore depobelt. In *SPE Nigeria Annual International Conference and Exhibition* (p. D021S008R001). SPE.

[40]. Onwuka, O.U., & Adu, A. (2024). Carbon capture integration in seismic interpretation: Advancing subsurface models for sustainable exploration. *International Journal of Scholarly Research in Science and Technology*, *4*(01), 032-041.

[41]. Onwuka, O.U., & Adu, A. (2024). Eco-efficient well planning: Engineering solutions for reduced environmental impact in hydrocarbon extraction. *International Journal of Scholarly Research in Multidisciplinary Studies*, *4*(01), 033-043.

[42]. Onwuka, O.U., & Adu, A. (2024). Subsurface carbon sequestration potential in offshore environments: A geoscientific perspective. *Engineering Science & Technology Journal*, *5*(4), 1173-1183.

[43]. Onwuka, O.U., & Adu, A. (2024). Sustainable strategies in onshore gas exploration: Incorporating carbon capture for environmental compliance. *Engineering Science & Technology Journal*, *5*(4), 1184-1202.

[44]. Onwuka, O.U., & Adu, A. (2024). Technological synergies for sustainable resource discovery: Enhancing energy exploration with carbon management. *Engineering Science & Technology Journal*, *5*(4), 1203-1213.

[45]. Pachaiappan, R., Rajendran, S., Show, P.L., Manavalan, K., & Naushad, M. (2021). Metal/metal oxide nanocomposites for bactericidal effect: A review. *Chemosphere*, *272*, 128607.

[46]. Pandian, B.A., Sathishraj, R., Djanaguiraman, M., Prasad, P.V., & Jugulam, M. (2020). Role of cytochrome P450 enzymes in plant stress response. *Antioxidants*, *9*(5), 454.

[47]. Psomas, G. (2020). Copper (II) and zinc (II) coordination compounds of non-steroidal anti- inflammatory drugs: Structural features and antioxidant activity. *Coordination Chemistry Reviews*, *412*, 213259.

[48]. Redrado, M., Xiao, Z., Upitak, K., Doan, B.T., Thomas, C.M., & Gasser, G. (2024). Applications of Biodegradable Polymers in the Encapsulation of Anticancer Metal Complexes. *Advanced Functional Materials*, 2401950.

[49]. Reif, B., Ashbrook, S.E., Emsley, L., & Hong, M. (2021). Solid-state NMR spectroscopy.

[50]. Sabzi, M., Mousavi Anijdan, S.H., Shamsodin, M., Farzam, M., Hojjati-Najafabadi, A., Feng, P., Park, N., & Lee, U. (2023). A review on sustainable manufacturing of ceramic- based thin films by chemical vapor deposition (CVD): reactions kinetics and the deposition mechanisms. *Coatings*, *13*(1), p.188.