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A COMPREHENSIVE REVIEW ON CHARACTERIZATION, SYNTHESIS, OF NANOMATERIALS AND ITS APPLICATION IN WATER TREATMENT

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ABSTRACT:

Nanomaterials offer unique properties that make them highly suitable for addressing water quality challenges. Understanding their characterization and synthesis is pivotal for optimizing their performance in water treatment applications. Various analytical techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and surface area analysis are discussed for nanomaterial characterization. Additionally, synthesis methods including physical, chemical, and biological approaches are explored in detail, highlighting their advantages and limitations. The review also delves into the diverse applications of nanomaterials in water treatment, including pollutant removal, disinfection, and membrane filtration. Moreover, recent advancements and emerging trends in the field are examined to provide insights into future research directions. This review provides a comprehensive overview of the characterization techniques, synthesis methods, and applications of nanomaterials in water treatment. Overall, this review serves as a valuable resource for researchers, engineers, and policymakers involved in the development and implementation of nanomaterial-based water treatment technologies.

Keywords: Nanomaterial, Characterization, Water treatment, Synthesis

1. INTRODUCTION

In the realm of science and technology, the emergence of nanoparticles has catalyzed a transformative revolution. Nanoparticles are essential elements in many fields, such as energy, semiconductors, medicine, and catalysis. They are described as being in the range of 1 and 1000 nm in size. Particles may behave differently from their bulk counterparts at smaller size scales. For instance, a particle's surface area significantly increases with particle size. This makes it possible for characteristics to emerge, such as higher magnetism, decreased melting temperatures, improved electrical and thermal conductivity, or distinctive optical qualities. The capacity to reliably use materials at this size offers a multitude of options for the creation of innovative materials in areas like clean energy, catalysis, and sensors, to mention a few. (R. Nagarajan., 2008) Nowadays, nanoparticles can be found in a large range of consumer goods. They can be used as coatings or fillers to provide UV protection, which is crucial for sunscreens, windows, and lenses. (W. J. Stark et al.,2015) Materials like silver and copper, which are known to have antibacterial qualities, can be used as nanoparticles to preserve food in packaging or to lessen sock odour. Gold nanoparticles have been investigated extensively in medicine as a possible tool for cancer detection and tailored medication administration. The significant increase in surface area that occurs when particle size decreases is the main factor driving the efficacy of nanoparticles for reaction

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catalysis when compared to bulk materials. This results in a catalyst material application that is far more efficient. (M. Rai et al.,2016)

Nanotechnology has the potential to significantly contribute to environmental protection and sustainability by providing innovative methods of cleaning and mitigating environmental pollutants. It can also help to reduce resource and energy usage by developing more efficient technology. Nanoparticles, for example, can be used to clean up oil spills, treat contaminated soil and groundwater, and absorb and remove contaminants from the atmosphere. Nanotechnology can also be used to build more efficient and effective ways for solar energy capture and storage, as well as biofuel production from renewable resources. (Ali Mansoori et al.,2008) Nanotechnology-enabled products, such as stronger and lighter materials, can help minimize energy usage in transportation and manufacturing. However, it is critical to examine the potential environmental and health consequences of nanotechnology and take steps to mitigate these risks. This includes ensuring that nanotechnology is produced and used in a responsible and sustainable manner, as well as subject to proper regulation and control. Nanotechnology can also be utilized to conserve raw materials and reduce greenhouse gas emissions, thereby contributing to environmental restoration. Nanotechnology-based solutions, for example, can remove radioactive waste from water, expand the water supply through cost-effective treatments, and help clean water by removing organic solvents in groundwater using iron nanoparticles. Nanotechnology can also be used to detect pollutants at the molecular level using accurate sensors, and to eliminate hazardous gases from the air, protecting people from harmful chemicals. (Coussens, C et al.,2005)

2. CLASSIFICATION OF NANOMATERIAL

Zero-dimensional (0D) nanoparticles have uniform dimensions across all three axes. Examples include spherical nanoparticles, quantum dots, and certain dendrimers. Their size is normally defined by their diameter, which can range from 1 to 100 nm. (Pandit, S et al.,2019)

One-dimensional (1D) nanoparticles have two dimensions at the nanoscale and one dimension that is much bigger. Examples include nanowires, nanorods, and nanotubes. Their size is normally defined by their length and diameter, which range from tens of nanometers to micrometres. (Su, B et al.,2012)

Two-dimensional (2D) nanoparticles have one dimension at the nanoscale and two dimensions that are much greater. Examples include nanoplatelets and graphene sheets. Their size is normally defined by their thickness, which can range from a few atoms to tens of nanometers. (Singh, V et al.,2011)

Composite nanoparticles are made up of various materials and can have dimensions along numerous axes. Core-shell nanoparticles are examples of composite nanoparticles with complicated shapes and architectures. Their dimensions are specified using the properties of their constituent materials and overall form. (Paras et al., 2022)

3. SYNTHESIS OF NANOMATERIAL

Numerous techniques, such as chemical reduction, coprecipitation, seeding, microemulsion, hydrothermal synthesis, and sono-electro deposition, can be used to create nanoparticles. (Nam NH et al.,2019) Chemical reduction is a wet-chemical process that uses

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dangerous reducing chemicals to reduce metal ions into uncharged nanoparticles. (Altammar, K. A. 2023) Nonetheless, there is a growing desire in creating environmentally friendly technology that relies on natural resources rather than risk-reducing chemicals. Green synthesis is the process of synthesizing nanoparticles utilizing biological processes since these processes are simple, inexpensive, safe, clean, and extremely productive. Several biological entities, including algae, yeast, plants, bacteria, actinomycetes, fungus, and fungi, are employed in the environmentally friendly creation of nanoparticles. (Altammar, K. A. 2023) The synthesis of silver nanoparticles has been extensively studied due to their unique properties, such as size and shape-dependent optical, antimicrobial, and electrical properties. A range of preparation methods, such as laser ablation, gamma irradiation, electron irradiation, chemical reduction, photochemical processes, microwave processing, and biological synthetic approaches, have been documented for the synthesis of silver nanoparticles. An overview of the manufacture of silver nanoparticles by physical, chemical, and biological synthesis is provided in the review paper by Prabhawathi et al., 2012 which also discusses the potential applications of these approaches in the future for various sectors. (Iravani, S et al.,2014)

The increasing need to create economically and environmentally sustainable techniques that do not include the use of hazardous chemicals in the synthesis protocols has led to a great deal of interest in bio-based methods for the synthesis of nanoparticles. When important factors, including types of organisms, inheritable and genetic properties of organisms, ideal conditions for cell growth and enzyme activity, ideal reaction conditions, and selection of the biocatalyst state, have been considered, bio-based protocols can be used to synthesize highly stable and well-characterized nanoparticles. Certain important factors, such as substrate concentration, pH, light, temperature, buffer strength, electron donor, biomass and substrate concentration, mixing speed, and exposure time, can be changed to influence the sizes and morphologies of nanoparticles. (Singh, J et al.,2018)

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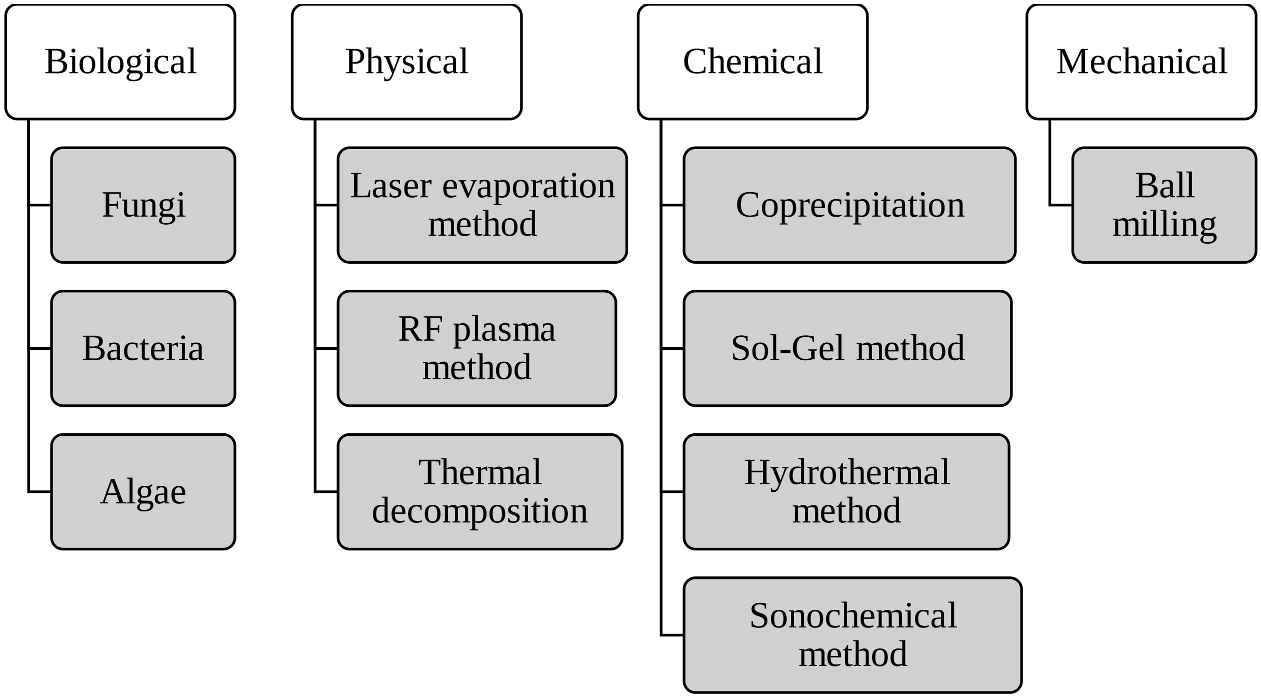

TECHNIQUES FOR SYNTHESIS OF NANOMATERIALS

4. CHARACTERIZATION OF NANOMATERIAL

S.NO	CHARACTERIZATION TECHNIQUE	PRINCIPLE	PARAMETERS IDENTIFIED	REFERENCE
1	Fourier Transform Infrared Spectroscopy (FTIR)	Analyzes molecular bonds by measuring absorbed infrared radiation frequencies.	Wavenumber, Absorbance, density, arrangement, mass, surface composition	(Paras et al., 2022)
2	Thermogravimetric Analysis (TGA)	TGA measures weight changes with temperature to analyze materials' composition.	material composition, stability, degradation kinetics, and thermal transitions.	(Bevis, J et al.,2008)

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3	Scanning Electron Microscopy (SEM)	Imaging surface topography using electron beam and detectors.	Crystal structure, NPs detection, optical properties	(Davydov, V. A et al., 2023)
4	Brunauer-Emmett-Teller (BET)	Surface area measurement by gas adsorption on porous materials.	Surface area, gas adsorption, pore size distribution, porosity characterization.	(Nasrollahzadeh, M et al.,2019)
5	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	Quantifies elements by ionizing atoms in plasma and detecting isotopes.	Sensitivity, selectivity, detection limits, resolution, precision, accuracy, robustness, throughput, stability, calibration.	(Loeschner, K et al., 2023)
6	X-ray Diffraction (XRD)	Analyzing crystal structure via X-ray scattering patterns.	Wavelength, crystal structure, lattice spacing, diffraction angle, peak intensity.	(Birkholz, M. 2006)

5. APPLICATION OF NANOTECHNOLOGY IN WATER TREATMENT

Nanotechnology has emerged as a viable subject for addressing water treatment concerns due to its unique nanoscale features and capabilities. Nanotechnology, which manipulates materials at the atomic and molecular levels, provides unique solutions for increasing the efficiency and effectiveness of water purification operations. One important application of nanotechnology in water treatment is the creation of nanomaterial-based filters and membranes. These nanoparticles have large surface area-to-volume ratios and customized surface characteristics, allowing them to effectively absorb and remove contaminants such heavy metals, pathogens, and organic pollutants from water streams. Furthermore, nanomaterials can be created to have certain capabilities, such as photocatalysis, which degrades contaminants under light irradiation, hence improving water purification operations. Furthermore, nanotechnology enables the design of improved oxidation processes. (AOPs) for water treatment, in which nanoscale catalysts are used to enhance the breakdown of persistent contaminants via oxidation processes. This method provides a sustainable and energy-efficient solution for treating wastewater and remediating contaminated water sources.

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NANOMATERIAL	APPLICATION	NOVEL APPROACH
Carbon nanotubes	Point-of-use, heavily degradable contaminants	Ultralong carbon nanotubes with extremely high specific salt adsorption
Polymeric nano adsorbents	Removal of organics and heavy metals	Biodegradable, biocompatible, nontoxic bio adsorbent
Zeolites	Reduced active surface through immobilization of nano silver particles	Nano zeolites by laser induced fragmentation
Nanosilver and nano-TiO2	Point-of-use water disinfection, antibiofouling surfaces, decontamination of organic compounds, remote areas	TiO2 modification for activation by visible light, TiO2 nanotubes
Magnetic nanoparticles	Groundwater remediation	Forward osmosis
Nano zero-valent iron	Groundwater remediation	Entrapment in polymeric matrices for stabilization
Nanofiltration membranes	Reduction of hardness, color, odor, heavy metals	Sea water desalination
Nanocomposite membranes	Highly dependent on type of composite, eg, reverse osmosis, removal of micropollutants	Bio-nanocomposite membranes
Nanofiber membranes	Filter cartridge, ultrafiltration, prefiltration, water treatment, stand-alone filtration device	Composite nanofiber membranes, bionanofiber membranes

Gehrke, I et al., 2015)

6. CONCLUSION

In conclusion, this comprehensive review has provided a detailed examination of the characterization techniques, synthesis methods, and applications of nanomaterials in water treatment. The characterization of nanomaterials is crucial for understanding their properties, morphology, and structure, which directly impact their performance in water treatment processes. Various analytical techniques such as SEM, TEM, XRD, FTIR, and surface area analysis play pivotal roles in characterizing nanomaterials with precision and accuracy. Synthesis methods play a significant role in

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tailoring the properties and functionalities of nanomaterials for specific water treatment applications. Chemical synthesis, physical methods, and green synthesis routes offer versatile approaches to engineer nanomaterials with desired characteristics such as size, shape, surface chemistry, and stability. The choice of synthesis method depends on the desired properties and intended applications of nanomaterials in water treatment. Nanomaterials exhibit exceptional properties such as high surface area, tunable reactivity, and unique electronic and optical properties, making them highly promising for various water treatment applications. Their applications include pollutant removal, disinfection, sensing, and remediation of contaminated water sources. Nanomaterial-based adsorbents, membranes, catalysts, and photocatalysts have shown remarkable efficiency in removing a wide range of contaminants such as heavy metals, organic pollutants, pathogens, and emerging contaminants from water. Despite their promising potential, challenges such as scalability, cost-effectiveness, environmental impacts, and potential risks associated with nanomaterials need to be addressed for their widespread deployment in water treatment technologies. Further research is warranted to optimize the synthesis methods, enhance the stability and recyclability of nanomaterials, and evaluate their long-term impacts on human health and the environment.

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