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INDEX

BASIC CONCEPTS OF NANOTECHNOLOGY

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Summary

Nanotechnology refers to objects that are one-billionth of a meter in diameter (nanometer). It is the emerging area of science and technology during the last 15 years. Among the nano materials nanotubes and powders were extensively used for various applications. Quantum dots are termed synthetic atoms and it has immense potential in medicine as bio sensors. Nanomaterials were synthesized by either top-down or bottom up principles and its characterization the sophisticated instruments like SEM, TEM, XRD, AFM etc. were used. This article described in brief about various application in different fields of nanomaterials in research.

Introduction

Science and Engineering research are experiencing a boom in the field of nanotechnology. It has replaced the high temperature super conductivity and laser evolution. This has made a new revolution in science and technology. During 1974 a Japanese scientist Taniguchi introduced the term nanotechnology for everyday life in a conference of the Japan Society of Precision Engineering. Although the chemists were extensively carrying out research in nanotechnology last two centuries. In Yu's view, nanotechnology, when viewed broadly, encompasses a realm of scientific endeavors focused on the synthesis, exploration, and application of devices, materials, and technical systems whose operations are influenced by nanostructures—ordered fragments typically ranging in size from 1 to 100 nanometers. The implication of this definition on the term “nanotechnology” is understood not only as a technological process of manufacturing of nanomaterials, objects and systems of nano meter sizes, but it also refers to the activities associated with the construction and investigation of nano systems. The initial individual to highlight the significance and optimistic prospects of nanoparticle exploration was the Nobel Prize-winning American physicist, R. Feynman. In his lecture titled "There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics," presented on December 29, 1959, at the California Institute of Technology, Feynman addressed the challenge of controlling substance structure at the scale of ultra-small distances. Feynman emphasized the potential impact of having control over the arrangement of elements on a small scale. He stated that with such control, there would be a significantly expanded range of possible substance properties and diverse capabilities. Furthermore, Feynman suggested that developing the ability to observe and manipulate things at an atomic level could offer substantial assistance in addressing challenges in the fields of chemistry and biology. By the last decade of the 20th century, the scientific community began to realize the promise of nanotechnology, and as a result, nano research grew tremendously. Global governments invested huge amounts in this field and this had lighted new applications of nano materials for thebeneficial of the world.

Nanotechnology:

Nanotechnology involves entities measuring one billionth of a meter in diameter, referred to as a nanometer. Its fundamental concept is that materials, which exhibit specific properties at their regular sizes, manifest various beneficial properties and functions when they are at a nanoscale. Take sunscreen, for instance; at its standard size, it is a creamy and potentially messy lotion, while at the nano scale, it can be aerosolized and applied as a fine mist on the skin. The primary goal of nanotechnology is to augment surface area by generating exceedingly small particles, leading to increased interactions with other particles. In essence, nanotechnology encompasses the manipulation and fabrication of matter ranging in size from 1 to 100 nm.

Classification Of Nano Materials

Nanostructured materials can be categorized according to the recommendations put forth by the 7th International Conference on Nanostructured Materials. The classification includes:

- Nano particles
- Nano porous structures
- Nano tubes and nano fibers
- Nano dispersions
- Nano structured surfaces and films
- Nano crystals and clusters.

Among the above classification, nanoparticles, nano tubes, and nano fibers hold significant economic importance and find extensive applications.

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Carbon Nano Materials

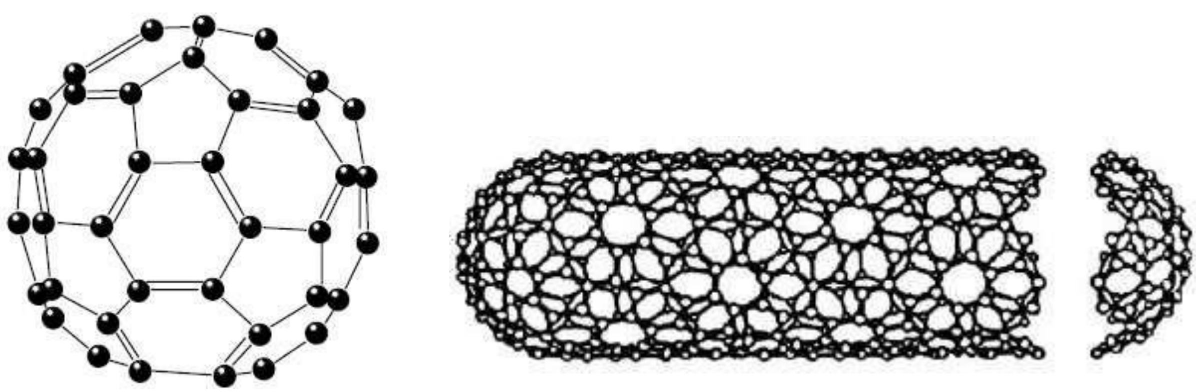

Fig 1. A) Fullerene C60 molecule B) A single layer nano tube model

Carbon nano materials, mainly fullerenes and carbon nanotubes are widely used for different applications. In 1985, Robert Curl, Harold Kroto, and Richard Smalley made the groundbreaking discovery of fullerene. Fullerene is a large molecule comprised of pentagons and hexagons, resembling footballs with an empty core (see Fig 1). The carbon atom count in fullerenes varies from 20 to several hundreds. Carbon nanotubes, unveiled by Sumio Lijima, exhibit quasi-one-dimensional tube structures formed by seamlessly wrapping the fundamental planes of a graphite hexagonal lattice into cylindrical shapes. Carbon nanotubes, whether single or multi-layered, have the capability of being opened and closed. In closed CNT the lid is half of fullerene molecule C60. The diameter of the CNTs varied from 0.5 (single layered) to 100nm in the case of multi layered structures. Nanotubes of SiC, BN, MoS, WS_2, V2O5, TiO2 etc. Owing to their topology, carbon nanotubes lack free chemical bonds; in spite of their diminutive sizes, they do not exhibit surface effects. Extensive research has been conducted on carbon nanotubes, with countries such as Japan engaging in commercial production, manufacturing hundreds of tons of CNTs.

Quantum Dots

Quantum dots are artificial atoms, whose properties can be controlled. Quantum dot is a conductor or semi conductor fragment having a three dimensional structure, with size of a few nanometers which can hold a certain number of electrons (around 100or less). An electron ina quantum dot is having many discrete quasy-stationary energy levels and it behaves as a particle in three dimensional potential box. Like atoms such system can transit from one energy level to another by emitting photons. The photon frequency can easily controlled by changing the size of the quantum dots. The most promising method of forming ordered arrays of quantum dots is based on the phenomenon of self-organization (self-assembling) of alien atoms on crystal surfaces and in solutions. If we succeed in creating quantum dots of the size of a few nanometers, then it will be possible to create single- electron devices working at room temperature. The operation of such devices would be based on a controlled movement ofindividual electrons.

Synthesis Of Nano Materials

Two commonly utilized methods for synthesizing nanomaterials are the top-down approach and the bottom-up approach. The bottom-up technique involves creating nanomaterials with the desired structure directly from the fundamental building blocks, such as atoms, molecules, and structural elements.Here we have to identify the desired materialin advance (eg, synthetic bone hydroxyapatite), ingredients like, titanium dioxide nanotubes, calcium phosphate, calcium hydroxide are placed together under ideal conditions in chlorides of sodium and potassium and magnesium carbonate/sulfate bath. Through a combination of self-direction and technical manipulation, molecules come together to form a complex product known as synthetic bone hydroxyl apatite. In a similar fashion, carbon nanotubes are created by directing simple carbohydrates (e.g., acetylene) through a volume containing catalysts at temperatures ranging from 600 to 800 degrees Celsius, resulting in the formation of CNTs on the catalysts.

The top-down approach involves the development of nanomaterials by reducing larger-sized particles to smaller sizes. Solid-state methods within these approaches transform insular materials into conductive substances. Atomic force microscopy facilitates the strategic placement of chemicals on materials to facilitate their modifications. The transformation of large materials into nanoscale dimensions imparts unique characteristics; for instance, nanosized aluminum exhibits the property of combustion. In the future, controlled nanoparticles of aluminum could potentially be employed to address conditions such as atherosclerotic plaques, calcifications in soft tissues, or tumors.

Equipments For Testing Nanomaterials

Nanotechnology holds the potential to transform diverse fields, including medicine, food science and technology, recreation and sport sciences, and civil engineering. Nanotechnology is an affordable technology eventhough it requires few number of costly equipments. A mere $500 investment can secure the essential chemicals, nanotubes, and nanoparticles required for basic work in a suitable laboratory. This is a modest expenditure when contrasted with the projected $1 trillion return in market shares anticipated from nanotechnology applications by 2015. Instruments employed for nanomaterial characterization encompass Transmission Electron Microscopes, Scanning Electron Microscopes and their variations like Scanning Tunneling Microscope, Near Field Scanning Optical Microscope, X-Ray Diffraction, Atomic Force Microscopes, FT Raman Spectroscope, UV-Vis Spectrophotometers, Particle size analyzers with zeta potential, among others.

The Characterisation of Nano materials

The characterization of nano materials is crucial as nanostructures exhibit intriguing physical and chemical characteristics. The effective utilization of nanotechnology necessitates a meticulous examination of their properties, encompassing mechanical, thermophysical, electrical, magnetic, optical, and chemical aspects. In-depth information on these properties can be found in various textbooks on nanotechnology.

Applications Of Nano Technology

1. **Electronics and instrumentation engineering**: CNTs used for compact sources for Roentgen radiation, luminescent lighting lamps, microwave radiation sources etc. CNTS used for preparing unique needle point of AFM and research is going on to develop modified nanotubes with specially selected functional groups at the needle points. In this case one can investigate not only the relief of a surface but also its chemical composition.

2. **Material science**: In the realm of material science, a significant application involves the creation of novel materials. CIFT is actively engaged in researching the formulation of new aluminum metal matrix composites through the inclusion of nano cerium oxide, nano samarium oxide, nano titanium oxide, and similar substances. Additionally, investigations have been conducted to manage the fouling of fishing gears employed in aquaculture and cages by applying nano materials. Manufacturing of fire-resistant materials by reinforcing nanomaterials in plastics. Development of thin anticorrosive coatings to protect the materials from degradation.

3. **Medicine and bio nanotechnology**: For the precise drug delivery, nanomaterials can be used when medications are transported to specific internal organs and tissues by carrier molecules. Synthesis of new biomaterials including substitutes for human body tissues, this will allow one to repair the human body.

The design of nanosensors and nano devices is instrumental in creating autonomous systems or those administered within the human body which facilitates identification of molecules with specific characteristics, such as cancer, and supports its subsequent treatment. Nanotechnology also plays a pivotal role in developing biomimetic mechanisms that enable the ongoing monitoring of a patient's health status. Furthermore, it facilitates communication with healthcare professionals and the execution of medical treatments as prescribed by physicians. Advancements in medical diagnostics and interventions fueled by nanotechnology have the potential to reshape practices in medical nutrition therapy. For instance, an engineered biodegradable material at the nanoscale, containing insulin, helps the individuals with type 1 diabetes mellitus provides flexibility to regulate their diet plans. This innovation releases insulin according to the requirement, responding to blood glucose concentrations. Ongoing research aims to gain a deeper understanding of the inflammatory processes associated with Crohn's disease and ulcerative colitis. This knowledge will pave the way for the direct application of anti-inflammatory agents derived from nanotechnology to the mucosal lining, thereby treating and preventing future attacks. The application of nano pharmaceuticals in resolving inflammatory bowel disease might expand food tolerances and choices for affected individuals. Nanotechnology is extending the horizons of cancer identification and potential treatment modalities. This includes improved diagnostic tools capable of detecting and visualizing very small tumors, Nano sensors identifying specific cancer markers in serum, and Nano shells delivering chemotherapy precisely to targeted locations. The transformative impact of nanotechnology on oncology suggests that future cancer treatments may be more targeted and of shorter duration, potentially influencing dietary interventions.

4. **Dietetics practice**: Examination and application of very small materials may sound better left to engineers, physicists, and chemists, but nanotechnology is expected to impact many aspects of daily life, including dietetics practice. Imagine an antibacterial nanomist, containing reactive nanoparticles so finely created so as to be unobtrusive to the human body, which can knock out *Escherichia coli* from fresh spinach or other foods at the point of harvest. Food packaging materials that detect *E coli* and other contaminants and that prevent spoilage are already being developed. These nanoproducts can transform purchasing, storage, and preparation specifications and hazard analysis critical control point activities in the food management arena.
5. **Food science**: Nanotechnology stands poised to reshape nutrient intake by expanding the array of enriched and fortified food products. This is expected to contribute to the growth of the functional food market, fueled in part by the proliferation of nutrient delivery systems facilitated by nanotechnology mechanisms. Antioxidant nutrients, for instance, can be incorporated into various nanomaterials such as nanocomposites, nanoemulsions, nanofibers, nanolaminates, nanofilms, or nanotubes. While the increased intake of micronutrients from an enhanced food supply holds potential benefits for the general population, vigilance by food and nutrition professionals is necessary to monitor against nutrient overconsumption and signs of toxicity in individuals. Micronutrient imbalances may also become more prevalent.

Social Issues

Societal implications of nanotechnology, like any emerging technology, remain uncertain. For instance, the consequences of the byproducts of nanoshells or nanoparticles used in cancer treatment entering circulation and healthy tissues are unclear. Questions arise regarding the need for medical treatment and nutrition therapy to address potential new diseases or conditions. Titanium dioxide nanoparticles, found in sunscreen, are susceptible to free radical formation when exposed to sunlight. Bement categorizes the societal impact of nanotechnology into three domains: environment, health, and safety; education; and ethical, legal, and other social issues. While nanotechnologists generally agree that nanoengineered DNA or subcellular nanoparticles are unlikely to have self-promulgation capabilities, concerns persist about the unregulated use of these nanomaterials in disease prevention and treatment. Maynard and colleagues advocate for the concurrent development of environmental and human health monitoring and alerting systems with specific nanotechnologies, challenging the "wait-and-see" approach. Broader issues encompass potential applications of nanotechnology in warfare, information transfer, security, and privacy, agricultural sustainability, and economic equity. The ethical and legal dimensions of nanotechnology necessitate public consideration, emphasizing the importance of raising awareness and understanding through public deliberations, discussions, and informed decisions by both the public and government for a promising future.

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SYNTHESIS OF NANOPARTICLES

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Introduction

Understanding various techniques for synthesizing nanoparticles is crucial for achieving desired particles with specific sizes and shapes. Nanotechnology encompasses two main synthetic methodologies: the Top-down approach and the Bottom-up approach. Further categorization of synthesis reveals three distinct methods: the physical method, the chemical method, and the biological method.

Before going into the detailed study of the synthetic methods of nanoparticles, there are various factors, which must be taken into consideration while synthesizing and characterizing nanoparticles. They are,

1. **Temperature:** It is an important parameter, which affects the synthesis of nanoparticles by physical, chemical, and biological methods. For physical approaches, high temperatures above 350°C are necessary. Chemical methods work at temperatures below 350°C, while biological methods rely on ambient or under 100°C temperatures. The temperature of the reaction medium dictates the characteristics of the resulting nanoparticles.

2. **Pressure:** Pressure serves as a crucial parameter in nanoparticle synthesis. The pressure applied to the reaction medium directly influences the resulting nanoparticles in size and shape.

3. **Time:** The quality and type of synthesized nanoparticles are determined by the duration of incubation of the reaction medium.

4. **Particle size and shape:** Particle size significantly influences nanoparticle properties. For instance, when the particle size get decreased the melting point of the nanoparticles also decreases, and the colour of the emitted light alters with changes in size. The shape of the synthesized nanoparticles plays a crucial role in their chemical characteristics.

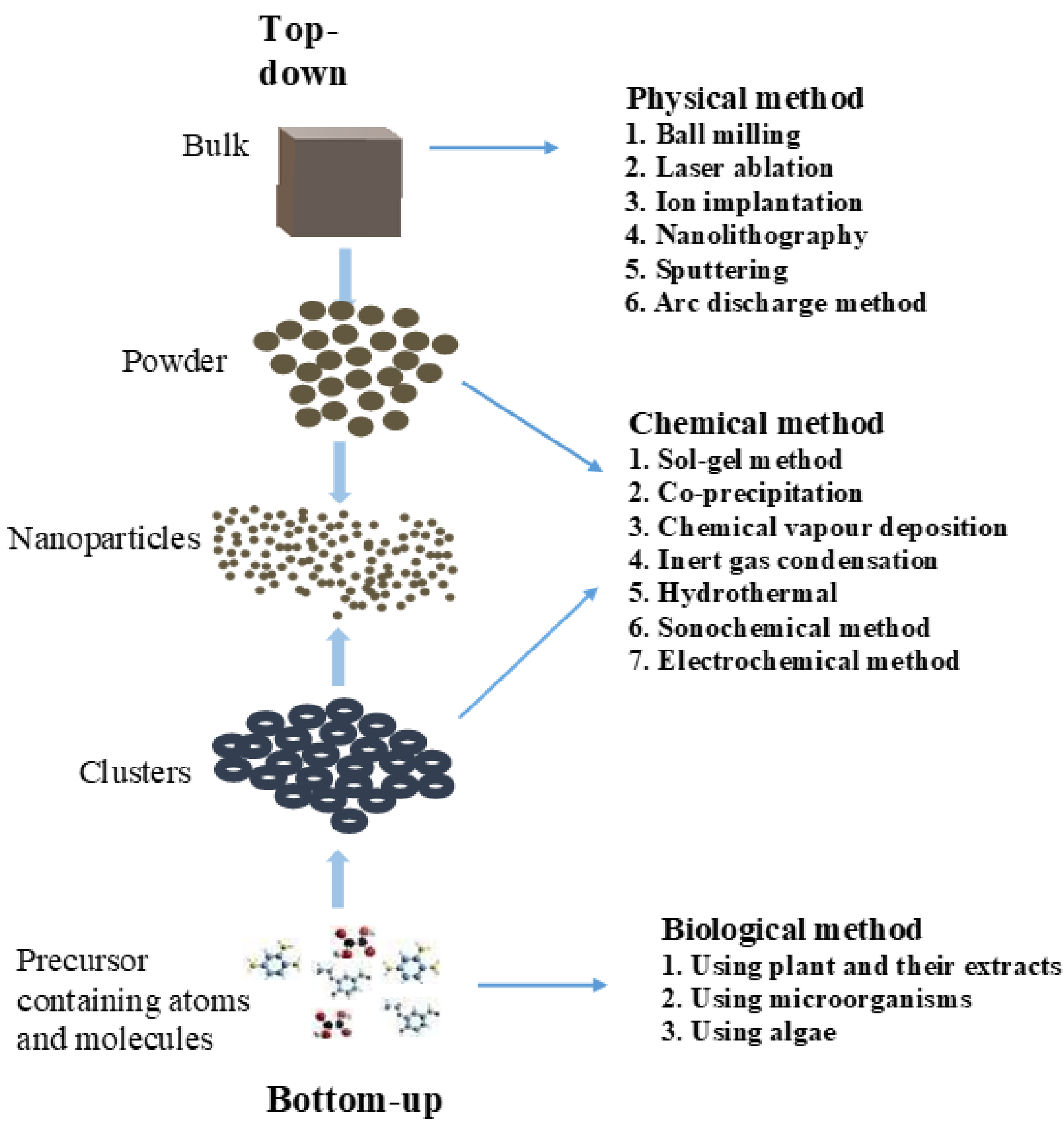
5. **Cost of preparation:** The cost of producing nanomaterials significantly impacts their potential applications. Regulating and controlling synthesis costs is essential to enable mass production and practical use. Chemical methods offer high yields but are not cost-effective, while physical methods are expensive. In contrast, biological synthesis is cost-effective, makingit suitable for large-scale nanoparticle production.

6. **Pore size:** Nanoparticle quality and applications are significantly impacted by their porosity, especially in applications like drug delivery, such as in cancer treatment.

7. **p^H Value:** p^H plays a significant role in nanoparticle synthesis by chemical and biological methods. It has been noted that the p^H of the solution medium impacts nanoparticle size and texture. This allows for size control by adjusting the solution's pH, particularly in the biological method.

8. **Environment:** The surrounding environment greatly affects the nature of the nanoparticles synthesized. Environmental factors like absorption and reactions impact nanoparticle formation. For instance, in biological synthesis, nanoparticles develop a coating that results in increased thickness and larger size.

Synthetic Methodologies



A. Top- Down Approaches

The top-down approach involves starting with larger structures and reducing them to nanoparticles through a sequence of controlled operations. However, these methods have notabledrawbacks, primarily due to their need for extensive installations and significant capital investment for setup. They have proved to be expensive and unsuitable for large-scale production, making them better suited for laboratory experimentation. This approach relies on a grinding process, making it less suitable for soft samples. Moreover, this method can cause imperfections in surface structure, and substantially impact the physical and other properties of nanoparticles. The common methods involved in the top-down approach are as follows, , Chemical vapour deposition, Physical vapour deposition , , Electron beam lithography, and X-Ray lithography Ion implantation

B. Bottom-Up Approaches

The bottom-up approach involves constructing nanomaterials by assembling molecules by molecules, atoms by atoms, and clusters by clusters. Physical forces drive particles to combine, resulting in larger structures. This technique is favored for creating complex nanostructures due to its precise control over particle size, leading to enhanced optical, electronic, and other properties. This method, also known as the constructive approach, entails building material from atoms to clusters to nanoparticles.

Bottom-up approach relies on a concept called molecular recognition (self-assembly, self-assembly is when things of the same kind come together naturally). Starting materials for this method can be either liquids or gases. Compared to the top-down method, bottom-up approaches can create devices at once and are more affordable, but they become challenging when thedesired structure gets larger and more complex. The common methods involved in the bottom-upapproach are as follows, Colloidal precipitation, Sol-gel synthesis, Hydrothermal synthesis, Electrodeposition, and Organometallic chemical route.

Method Of Synthesis

1. **Physical methods**: There are number of physical methods for the synthesis of nanoparticles. These techniques operate at elevated temperatures, usually greater than 350°C.

2. **Chemical methods**: These are simple and affordable methods for producing nanoparticles. They typically involve working at temperatures below 350°C. The production of large amounts of materials is possible featuring a variety of particle sizes and shapes.

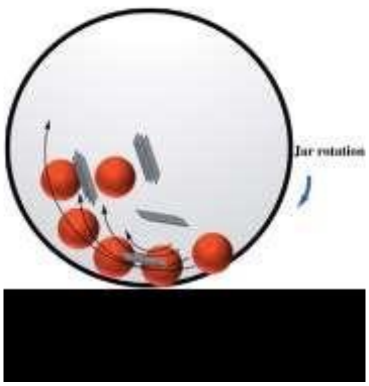
3. **Biological methods**: Biological methods involve utilizing microorganisms such as fungi,bacteria, yeast, etc., plant extracts (or enzymes), or templates such as DNA, viruses, and membranes. This approach is also called "green synthesis" because of its minimal toxicity and eco-friendly nature.

The choice of nanoparticle synthesis methods depends on specific requirements. Each method has its own advantages as well as disadvantages, and the selection depends on available resources. Physical methods are good for small-scale production, while chemical methods are chosen for cost-effective production. Biological methods have their own unique significance.

1. **Physical Method**

Mechanical Method

Ball Milling



The ball milling method presents a straightforward and cost-effective approach for synthesizing nanoparticles. In this method, a mill chamber, typically constructed from stainless steel, contains numerous small balls made of materials such as iron, hardened steel, tungsten carbide or silicon carbide. These balls rotate inside the mill, facilitating the synthesis process. The chamber is filled with either inert gas or air and rotated rapidly around its central axis. Material is converted into nano-size by compressing it between the container walls and balls. The ball-to-material mass ratio is normally maintained at a 2:1 ratio. The process is not so sophisticated, therefore the shape of the nanomaterial is irregular and produces crystal defects.

Laser Ablation (LA)

Laser ablation is a complex top-down approach where laser light penetrates a sample's surface, causing the removal of electrons from the material. The interaction between generated free electrons and bulk sample atoms transfers energy, leading to surface heating and vaporization. With high laser flux, the material transforms into a plasma state containing atoms, molecules, ions, and clusters. The pressure contrast between seed plasma and atmosphere drives rapid plasma expansion and cooling. LA takes place in a vacuum or gaseous environment and can be improved using a tube furnace to control growth conditions better.

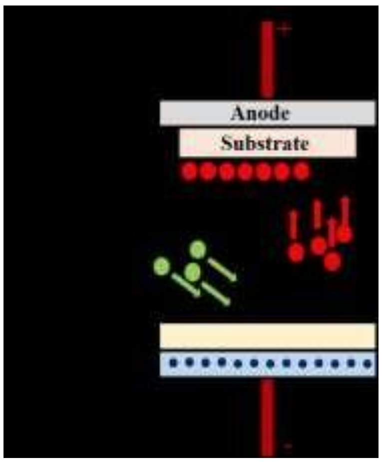
Ion Implantation

Ion implantation is employed to alter the existing surfaces of materials. This technique involves directing high-energy ions with electrostatic charges (ranging from 10 to 100 Kev) toward the surface. These ions carry kinetic energies much greater than the binding energy of the host material, allowing them to be implanted in a surface layer, often several nanometers in thickness.

Nanolithography

Lithography is a top-down approach, which involves patterning a sample by removing certain parts or arranging materials on a suitable substrate. Often combined with deposition and etching, it achieves high-resolution topography. Lithography can be categorized as masked or maskless. In the realm of masked lithography, patterns are generated through the utilization of masks or molds, encompassing techniques like photolithography, soft lithography, and nanoimprint lithography. Conversely, mask less lithography methods, such as electron beam lithography, scanning probe lithography and focused ion beam lithography produce arbitrary patterns directly without the need for masks or molds. Nanolithography's key advantage is producing desired shapes and sizes, from single nanoparticles to clusters. However, complex equipment and costs are drawbacks.

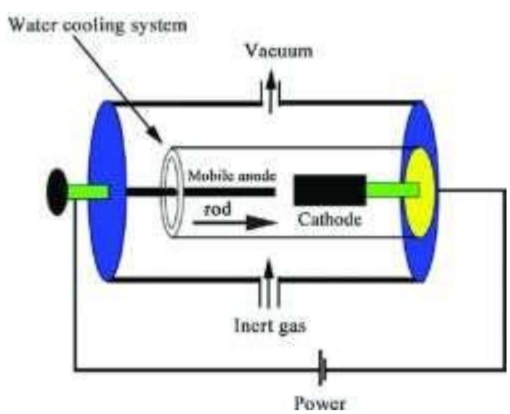
Sputtering



Sputtering

Sputtering involves depositing nanoparticles onto a surface through the collision of particles with ions, ejecting them from thesurface. This often leads to the deposition of a thin nanoparticle layer followed by annealing. Typically, argon plasma is used for this process. Factors like layer thickness, annealing conditions, substrate type, etc., determine the nanoparticle's size and shape.

Arc Discharge Method



Arc Discharge method

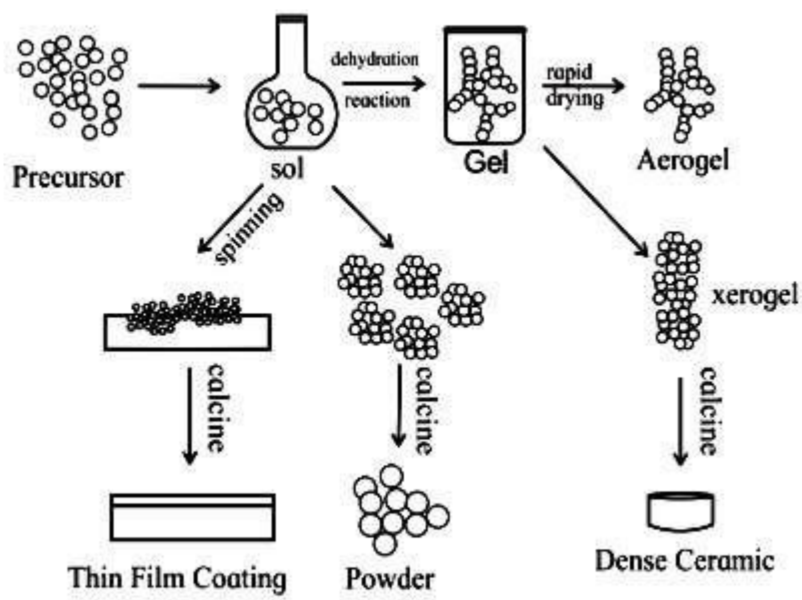
Arc discharge method is a popular technique for synthesizing nanoparticles. It involves creating a high-energy electrical discharge between two electrode materials in an inert gas environment. The intense heat generated by the arc vaporizes the electrode materials, producing a plasma plume rich in vaporized atoms and ions. As the plasma cools down rapidly, these species condense and nucleate, forming nanoparticles. The method is widely used for producing carbon-based nanoparticles like carbon nanotubes and fullerenes. It offers control over nanoparticle size, structure, and composition by adjusting experimental parameters such as electrode materials, discharge conditions, and gas environment.

2. Chemical Method

Sol-Gel Method

The sol is a liquid-phase mixture with suspended solid particles, while the gel is a solid structure immersed in a solvent. Sol-gel is a favored bottom-up approach due to its simplicity and wide applicability for nanoparticle synthesis. It falls under the liquid phase synthesis category and is particularly suitable for creating oxide nanoparticles and composite nano powders. The sol-gel technique involves various steps:

- Formulating a consistent solution involves decomposing metal-organic precursors within an organic solvent or organic salt solution.
- Transforming precursor oxide into a robustly interconnected solid structure.
- Hydrolysis yields a sol, wherein colloidal particles disperse in a liquid medium through the introduction of suitable reagents, commonly water.
- Sequential condensation processes lead to the formation of a gel, which evolves into a sturdy interconnected organic network.



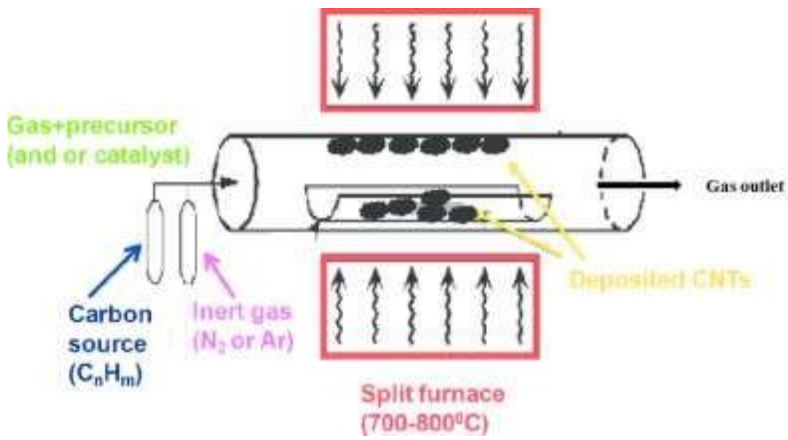
Sol-Gel

Co-precipitation

Co-precipitation is a frequently employed wet chemical method widely used for its simplicity, cost- efficiency, and reproducibility. It is also referred to as the solvent displacement method. For preparing nanoparticles, key components include a polymer phase, synthetic or natural, and a solvent like ethanol, acetone, and hexane, alongside a nonsolvent polymer. Nanoparticles are created by swiftly diffusing the polymer solvent into a nonsolvent polymer phase while mixing the polymer solution. The interfacial tension between these phases maximizes the surface area, leading to the spontaneous precipitation of nanoparticles.

Chemical Vapour Deposition (CVD)

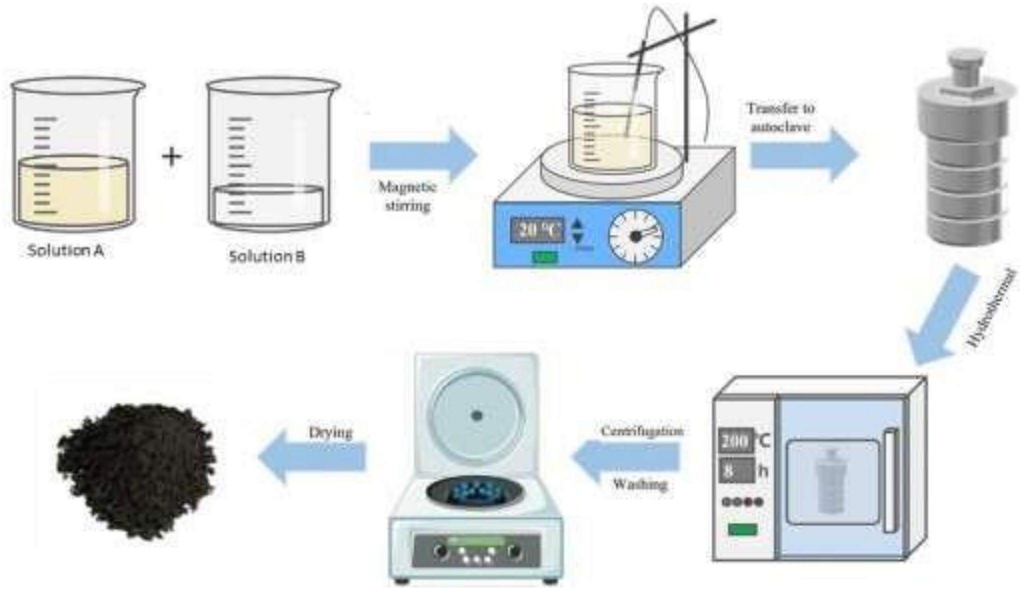
CVD is a top-down method employed to create nanostructures. It involves a chemical reaction between a heated substrate and a combining gas in a reaction chamber at room temperature, resulting in a thin film forming on the substrate's surface. The temperature of the substrate affects the process. CVD offers benefits like highly pure, uniform, durable, and robust nanoparticles. However, drawbacks include the need for specialized equipment and the production of highly toxic gaseous by-products.



Chemical Vapour Deposition

Inert Gas Condensation

This method is widely used for creating metal nanoparticles, where metallic sources evaporate in the presence of inert gas to produce fine nanoparticles at reasonable rates and attainable temperatures. This process is suitable for creating copper metal nanoparticles where, metal is vaporised inside a chamber filled with inert gases like argon, helium, or neon, causing the vaporized atoms to lose energy upon collision with the inert gas. The vapor undergoes cooling by liquid nitrogen, yielding nanoparticles with a size range of 2 to 100 nm.



Hydrothermal Synthesis

Hydrothermal Synthesis

Hydrothermal synthesis is a widely employed method to create nanomaterials and relies on a solution reaction approach. This process involves crystal nucleation and growth, resembling crystallization. Hydrothermal synthesis involves a broad temperature from room temperature to very high levels. Morphology control is achieved through low-pressure or high-pressure conditions based on the main composition's vapor pressure in the reaction. Temperature, pH, andreactant concentrations can be adjusted to influence particle morphology.

Sonochemical Synthesis

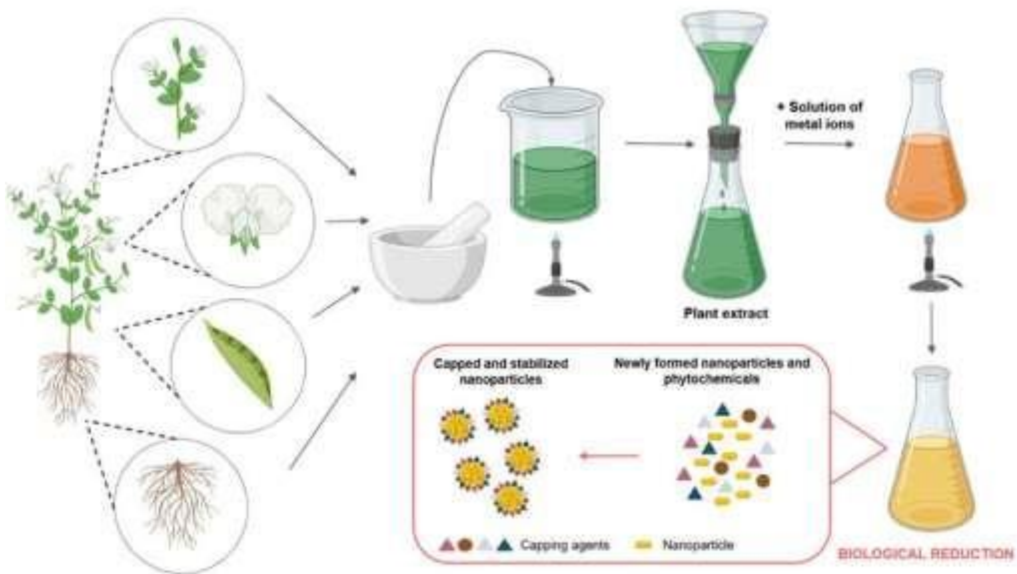
Sonochemistry, among the initial methods employed, entails chemical reactions prompted by intense ultrasound radiation ranging from 20 kHz to 10 MHz. This technique relies on acoustic cavitation to drive the process. Ultrasound proves to be a convenient means for synthesizing nanomaterials, offering distinct advantages in various nanomaterial-related domains: (1) generating amorphous products; (2) integrating nanomaterials into mesoporous materials; (3) applying nanoparticles onto ceramic and polymeric surfaces; and (4) managing the morphology of nanomaterials

Electrochemical Method

The electrochemical method for synthesizing nanomaterials involves the application of voltage to initiate chemical reactions within an electrolyte solution. This technique is adaptable to various materials and is employed in the production of metallic nanoparticles, whether with or without nanoporous hard templates. These templates, such as track-etched polymers or anodized aluminum oxides, are coated with a metal film that serves as a cathode for the electroplating process. The reduction and deposition of metal ions occur within the template pores, providing control over nanoparticle size and morphology through the adjustment of electrodeposition parameters. Electrochemical synthesis is particularly advantageous for crafting multicomponent nanowires. Additionally, electrospinning and electrodeposition serve as versatile methods for creating nanofibers from polymers, composites, and ceramics. This includes subsequent processes like calcination or carbonation.

3. Biological Method Synthesis using plant extracts

Plant extracts play a significant role in the biosynthesis of nanoparticles, a process known as green synthesis. Extracts from different plant parts like leaves, flowers, seeds, barks, fruits, and roots are used for creating nanoparticles, including silver nanoparticles. These plant extracts can also act as stabilizing and reducing agents during the synthesis process.



Nanoparticles synthesis from plant extracts

Synthesis Using Microorganisms

In recent times, the synthesis of nanoparticles using microorganisms has gained significant attention because of its economical nature and environmentally sustainable characteristics. Two methods for synthesizing nanoparticles from microorganisms are extracellular biosynthesis and intracellular biosynthesis. Some microorganisms have the ability to sequester metal ions, and various reductase enzymes present in these microorganisms can store and neutralize heavy metals. The process of nanoparticle formation by microorganisms includes capturing metal ions, enzymatic reduction, and capping. Initially, the metal ions are captured on the surface or inside the microbial cells, and subsequently, enzymes are employed to reduce them into nanoparticles.

Synthesis Using Algae

Algae-based nanoparticle synthesis is environmentally friendly, cost-effective, and has applications in various fields. This method involves preparing algae to extract in either aqueous or organic solvent through heat or boiling. A molar solution of an ionic metallic complex is then prepared. The algae solution and the metallic complex solution are incubated with or without stirring under controlled conditions. The synthesis of nanoparticles depends on the type of algae and is influenced by various factors, including biomolecules like peptides, pigments, and polysaccharides that contribute to metal reduction. Silver and gold nanoparticles are commonly synthesized using this approach.

Conclusion

The top-down approach is costly and unsuitable for soft samples. While it's not practical for large-scale production, it's well-suited for lab experiments. On the other hand, the bottom-up method depends on molecular recognition and involves building nanostructures atom by atom, molecule by molecule, or cluster by cluster. Various nanoparticle synthesis methods were explored.

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CHARACTERIZATION OF NANOPARTICLES

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Introduction

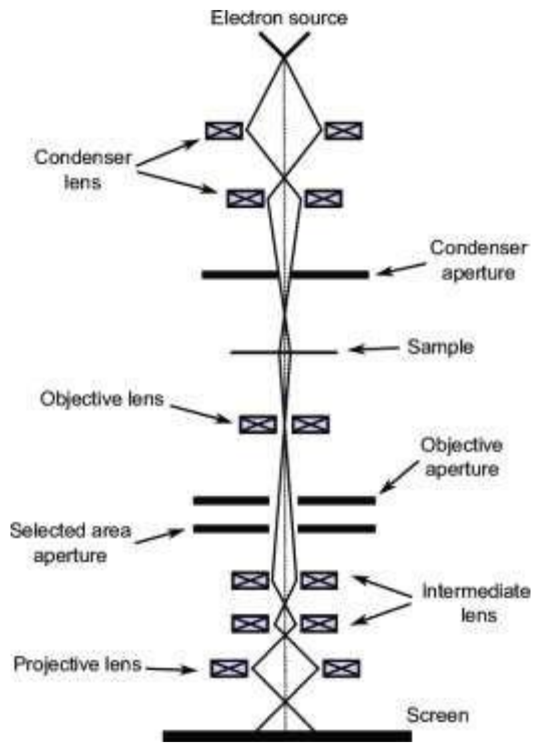
Nanomaterials have garnered significant attention as a rapidly expanding material category with diverse applications, necessitating thorough characterization. Various methods have been used to assess nanoparticle size, crystal structure, elemental composition, and other physical properties. Sometimes, multiple techniques can be used to evaluate specific properties. Choosing the most suitable method can be challenging due to the distinct advantages and drawbacks of each technique, often requiring a combined approach for complete characterization.

Morphology (Size, Shape, Length, Internal Structure)

Morphology stands out as a key factor in nanoparticle characterization. Nanomaterials' size and shape play crucial roles in shaping their physicochemical characteristics, influencing aspects such as catalytic activity, bioactivity, optical properties, magnetic properties, and mechanical properties. To analyze size, distribution, shape, and aggregation, widely used techniques include TEM, SEM, and AFM.

1. Transmission Electron Microscopy (TEM)

Transmission Electron Microscopy serves as a frequently utilized technique for characterizing nano materials. It employs a particle beam of electrons to observe specimens and produce highly magnified images. Operating on similar principles to a light microscope, TEM differs in using electrons rather than light. The electron wavelength being significantly smaller than that of light allows TEM to achieve optimal resolutions many magnitude superior to those achievable with a light microscope.



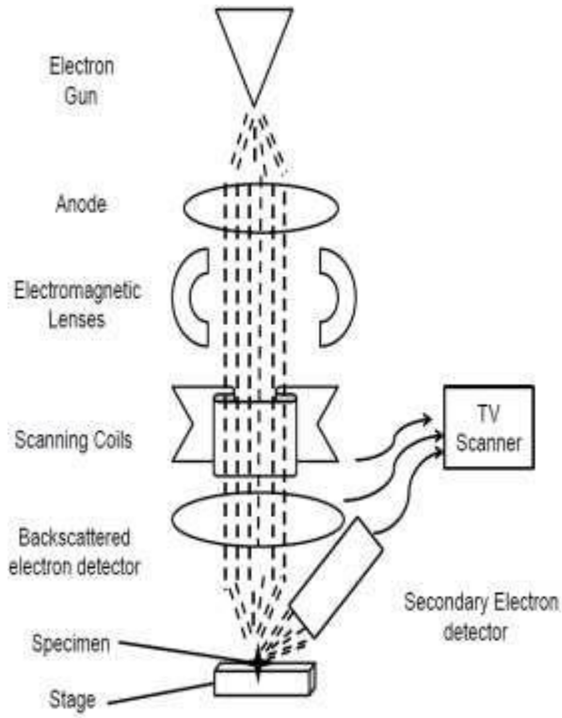
Schematic representation of TEM

Transmission electron microscopes (TEMs) utilize a high-voltage electron beam to generate an image. Positioned at the top of a TEM, an electron gun emits electrons that traverse the microscope's vacuum tube. Unlike light microscopes that use a glass lens for focusing, the TEM employs an electromagnetic lens to concentrate electrons into a finely focused beam. This electron beam then traverses through the exceptionally thin specimen, where electrons either scatter or strike a fluorescent screen located at the bottom of microscope. The resulting image of the specimen displays its various components in distinct shades corresponding to their densities.

High-Resolution TEM (HR-TEM) is a specialized imaging technique within TEM that enables direct visualization of a sample's atomic-level crystallographic structure. This method is instrumental for studying material properties at the atomic scale, revealing crystal structures, defects, and even individual atoms. HR-TEM is applicable in investigating crystal nanoparticles, their spatial arrangement, nanocrystalline features in amorphous films, alignment of nanofibers, and porous materials.

Despite its effectiveness in analyzing nanomaterial’s shape, size, heterogeneity, aggregation, and dispersion, TEM has certain limitations. One key drawback is its demand for high vacuum and ultra-thin sample sections, potentially altering the sample's structure during preparation. The high-energy electron beam in TEM can harm or destroy specimens, and artifacts may emerge when probing 3D specimens using a 2D transmission view due to limited depth sensitivity. Additionally, TEM's examination of a small specimen area over a specific period leads to poor statistical analysis.

2. Scanning Electron Microscopy (SEM)



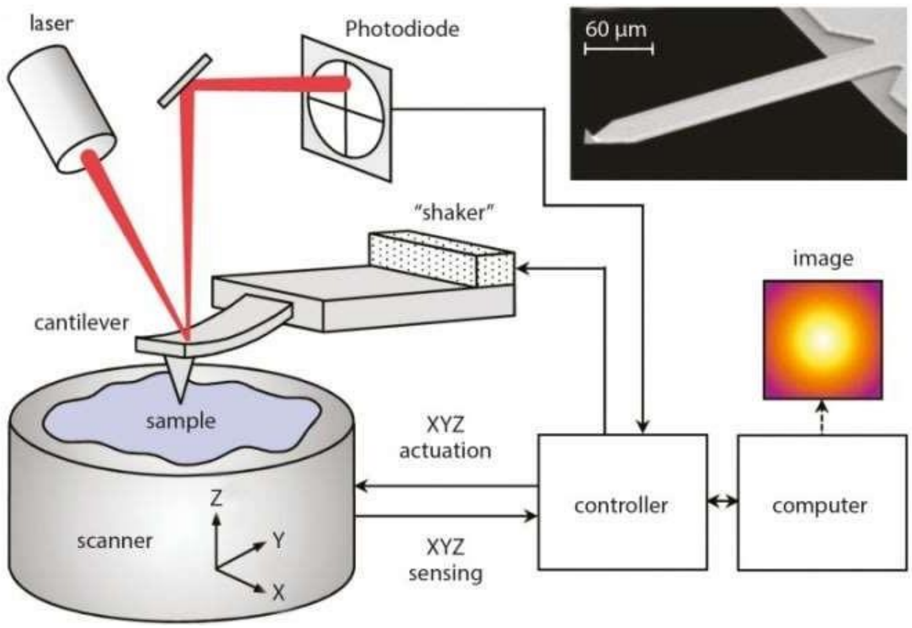
Schematic representation of SEM

A Scanning Electron Microscope (SEM) is an electron microscope that captures images of a sample through the scanning of its surface with a focused electron beam. This electron beam is systematically moved in a raster scan pattern, generating diverse signals that contain details about the sample's surface topography and composition. In SEM, electrons are generated at the apex of the high vacuum column and then accelerated toward the sample. The trajectory of electrons within the microscope column is regulated by the condenser and objective lens, converging the beam twice before it impacts the sample. The interaction of electrons with the sample produces backscattered (BSE) and secondary electrons (SE), which are utilized for SEM imaging. BSEs are part of the primary electron beam, while secondary electrons originate from the atoms of the sample. Various detectors are employed to capture these electrons, and the resulting data is utilized to create images.

The Field Emission Scanning Electron Microscope (FESEM), akin to the SEM, furnishes a wide range of information about the sample surface, but with enhanced resolution and a significantly expanded energy range.

Nevertheless, SEM measurements come with certain limitations. Sample preparation involving drying and contrast can lead to nanomaterial shrinkage, altering their size and shape characteristics. Additionally, because the scanning area contains limited number of particles, biased statistics regarding size distribution are unavoidable for heterogeneous samples.

3. Atomic Force Microscopy (AFM)



Schematic representation of AFM

Atomic Force Microscopy (AFM) proves to be a potent imaging technique, proficient in mapping the topography of thin film surfaces across a variety of materials. As a high-resolution method, AFM falls under the category of scanning probe microscopy, often referred to as scanning force microscopy (SFM). Its utility extends to assessing different forces, including adhesion strength, magnetic forces, and mechanical properties.

The operation of AFM microscopes involves the utilization of an exceptionally sharp tip situated on a micro-machined silicon probe for surface sensing. This tip scans the sample in a raster pattern, employing distinct methods across various operating modes, with the primary modes categorized as contact mode and dynamic (tapping) mode.

The fundamental concept of AFM revolves around a nanoscale tip connected to a small cantilever, forming a spring-like structure. Upon the contact with the surface cantilever undergoes bending due to the interaction with the tip. This bending is detected through a laser diode and a split photodetector, with the degree of bending serving as a measure of the interaction force between the tip and the sample.

During the scanning process of the sample, using a fine tip attached at the end of the cantilever, there are interactions such as attractive or repulsive forces, mainly Van der Waals forces, and other forces like electrostatic and hydrophobic/hydrophilic forces, between the tip and sample. These interactions lead to a bending of the cantilever. A laser is used to measure this deflection, which is reflected off the cantilever onto photodiodes. The photodiodes produce an output signal based on the varying light collected, indicating the vertical bending of the cantilever. This information is then directed to a scanner that controls the probe's height as it traverses the surface. The scanner's adjustments in height are utilized to generate a three-dimensional representation of the sample's topography.

Structural and Chemical Characterization

Characterization of nanoparticle's structure and composition holds great significance, as these factors strongly affect their physicochemical properties. The analysis of nanoparticle composition, phase, crystallinity, functionalization, chemical state (oxidation), surface charge, polarity, bonding, and electrochemical properties is commonly conducted using various techniques. Techniques used for structural and composition analysis include,

4. X-ray Powder Diffraction (XRD)

X-ray powder diffraction (XRD) stands out as an analytical technique primarily utilized for the phase identification of crystalline materials and can furnish information about unit cell dimensions. The material under analysis undergoes meticulous grinding and homogenization, followed by the determination of the average bulk composition.

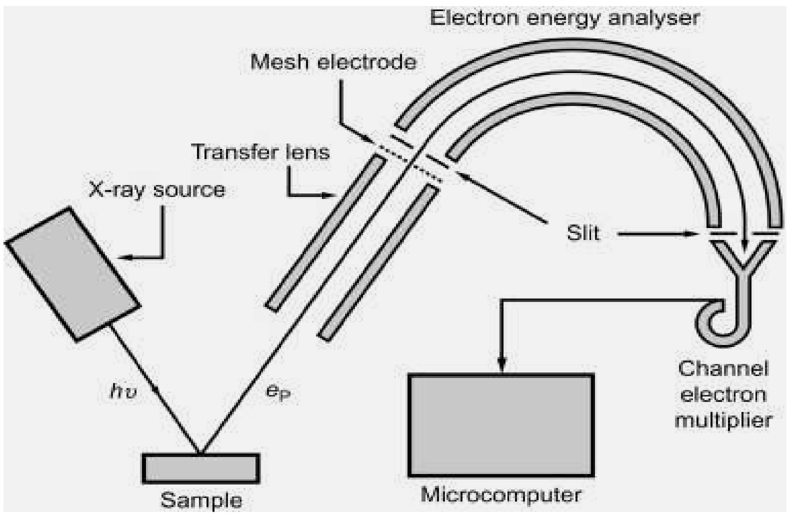
Crystalline substances serve as three-dimensional diffraction gratings for X-ray wavelengths that align with the spacing of planes within a crystal lattice. X-ray diffraction hinges on the constructive interference of monochromatic X-rays and a crystalline sample. These X-rays, emanating from a cathode ray tube, undergo filtration for monochromatic radiation, collimation for concentration, and are then directed toward the sample.

The interaction of incident rays and the sample results in constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). These diffracted X-rays are subsequently detected, processed, and tallied. Scanning the sample across a range of 2θ angles ensures the acquisition of all potential diffraction directions of the lattice. The conversion of diffraction peaks to d-spacings facilitates mineral identification, as each mineral possesses a distinctive set of d-spacings.

Generally, XRD provides limited information for anisotropic particles and those with uneven size distribution. In such scenarios, supplementary analyses like TEM are necessary for proper interpretation. Additionally, XRD cannot characterize individual particles, and the earlier equation discussed calculates the average particle size for the material rather than the specific particle size.

5. X- Ray Photo Electron Spectroscopy (XPS)

X-ray photoelectron spectroscopy (XPS) relies on the photoelectric effect to discern the elements present in a material, either constituting its elemental composition or coating its surface. Additionally, XPS provides insights into the chemical state, overall electronic structure, and density of electronic states within the material. The acquisition of XPS spectra involves irradiating a solid surface with an X-ray beam and concurrently measuring the kinetic energy of electrons released from the top 1-10 nm of the material under examination. The creation of a photoelectron spectrum involves counting the ejected electrons across a range of electron kinetic energies. Peaks in the spectrum correspond to atoms emitting electrons with specific characteristic energies. Through analyzing the energies and intensities of these photoelectron peaks, all surface elements can be identified and quantified, with the exception of hydrogen and helium, which lack core electrons.



Schematic representation of XPS

However, when conducting XPS analysis on nonconductive materials, special attention is necessary as these materialstend to induce undesired shifts in the energy spectrum.

6. Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR (Fourier transform infrared spectroscopy) is a quick and reliable method for identifying materials and quantifying their components in a sample. It is based on infrared spectroscopy and utilizes a wide range of infrared spectra (from Near Infrared to Far InfraRed) to gather information. Unlike a dispersive infrared spectrometer, where individual spectral components aremeasured one at a time, FTIR simultaneously collects all wavelengths, making it efficient and easy to use.

The fundamental of FTIR is rooted in the atomic vibrations of molecules that selectively absorb specific frequencies and energies of infrared radiation. Molecules behave like vibrating springs due to their interatomic chemical bonds, with energies close to infrared light. When molecules absorb infrared light, they vibrate. These vibrations are limited to those involving a change in dipole moment, and vibrations cancel out if bond vibrations between atoms oppose each other.

In linear molecules, symmetric stretching vibrations do not absorb infrared light because the dipole moment remains unchanged, while asymmetric stretching vibrations do absorb infrared light due to the dipole moment alteration. In nonlinear molecules, both symmetric and asymmetric stretching vibrations absorb infrared light as the dipole moment changes. Additionally, infrared absorption takes place for bending and rotational vibrations as long as the dipole moment changes.

The absorption spectrum of each molecule is distinct and can identify the molecule due to its absorption of infrared radiation at specific frequencies. Each molecular structure has a unique arrangement of atoms, so when it is exposed to infrared light, generates a unique spectrum. This is even true for molecules with the same number of atoms but varying positions. The infrared absorption spectrum acts like a distinct fingerprint for each molecule.

FTIR spectroscopy involves an IR beam passing through an interferometer, comprising a beam splitter, fixed mirror, and moving mirror. This device temporally separates the beam's spectral components. Afterward, the beam travels through the sample gas cell before reaching the detector. An interferogram is recorded, reflecting the detector signal over time, from which the corresponding absorbance spectrum is derived.

7.Characterization Of Optical Properties

Studying and characterizing the optical properties of nanoparticles is crucial, as these methods provide insights into the absorption, reflectance, fluorescence, luminescence, electronic state, bandgap, photo activity, and electrical conductance attributes of nanoparticles. In addition, these can be measured using,

7. 1. Ultraviolet-Visible Spectroscopy

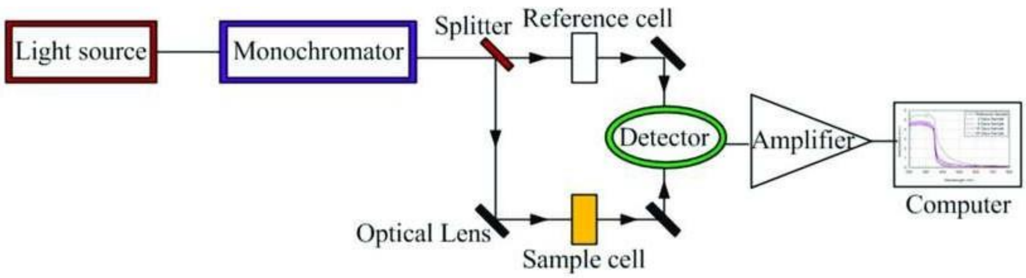
Ultraviolet-visible spectroscopy (UV-Vis or Spectrophotometry) involves analyzing the interaction of substances with light in the UV and visible regions of the electromagnetic spectrum. This technique measures the absorbance of light by a sample and helps quantify the substance present. It works by comparing the intensity of light passing through a sample to that of a reference, offering insights into material characteristics.

When light interacts with a substance, it causes electronic transitions where electrons move from lower energy states to higher energy states. This transition is linked to the absorption of ultraviolet or visible radiation, with the energy difference between ground and excited states matching the absorbed radiation. This relationship is the basis for deriving ultraviolet-visible (UV-Vis) spectra.

The Beer-Lambert law establishes a mathematical relationship between absorbance and concentration, enabling the direct determination of absorber concentration in a solution based on absorbance and a fixed path length.

As per the law, the absorbance of a solution is directly proportional to both the concentration of the absorbing substance and the path length. This means that as the concentration of molecules capable of absorbing radiation at a specific wavelength rises, the absorption increases. Moreover, a molecule's effectiveness in absorbing radiation, indicated by its molar absorptivity, also contributes to higher absorption.

In UV-Visible spectroscopy, electromagnetic radiation is emitted from a source and separated into different wavelengths by a monochromator. These wavelengths then pass through a beam separator, dividing them into reference and sample chambers. The radiation penetrates both samples, with some being absorbed by the sample and others transmitting. These transmitted radiations are processed to subtract solvent absorption. Finally, a detector records the transmitted radiation, and the resulting graph plots absorbance against wavelength for easier analysis by experts.



Schematic representation of UV- Vis spectroscopy

8. Fluorescence Spectroscopy

Fluorescence spectrophotometry involves analyzing a molecule's fluorescence based on its distinctive properties. Fluorescence is a form of photoluminescence that occurs when a molecule absorbs energy at a wavelength where it possesses a transition dipole moment. This absorbed energy transfer an electron to an excited state, which then releases thermal energy to the surroundings through vibrations, followed by the emission of a photon from the lowest-lying singlet excited state.

This technique involves illuminating a sample with specific light (typically ultraviolet or visible) that the sample's compounds can absorb. This excites the molecules from their ground state to anexcited electronic state. As the molecules return to the ground state, they emit energy in the form of photons, resulting in fluorescence. The emitted photons' intensities and frequencies are detected and analyzed, providing insights into the molecule's vibrational energy levels and offering information about the molecule's identity, quantity, changes, interactions within the sample, and more.

9. Characterization of Thermal Properties

Various methods are available to characterize the thermal properties of nanoparticles, such as melting points, crystallization, structural-phase transitions, heat capacity, thermal conductivity, and thermal and oxidative stability. Among these, Analysis (TGA) stands out as a primary technique for analyzing thermal properties.

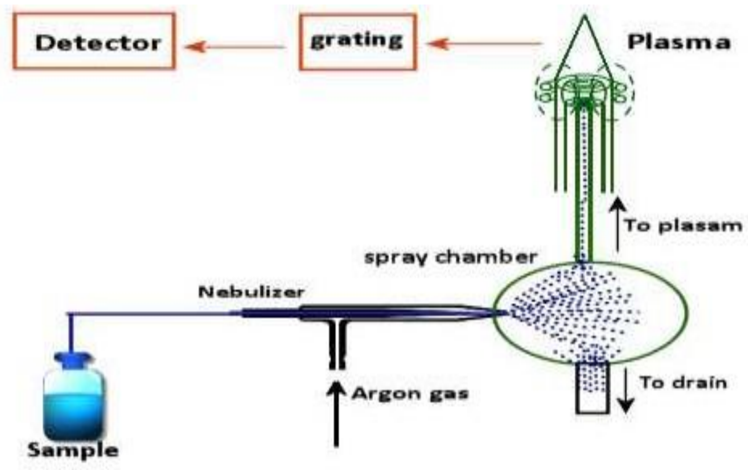
9.1. Thermogravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) is a robust method used to measure the thermal stability of various materials, including polymers. This technique involves tracking weight changes in a sample as its temperature is raised. TGA can also determine the moisture and volatile content within a specimen.

TGA operates by monitoring changes in the mass of a substance while subjecting it to continuous heating. While certain thermal processes like melting and crystallization may not influence mass, other thermal events such as desorption, absorption, sublimation, vaporization, oxidation, reduction, and decomposition can lead to significant mass changes. Hence, it is crucialto optimize the conditions and factors that influence the sample's mass change throughout the experiment.

In this technique, the sample is continuously weighed as it is heated from room temperature to 1000 degrees Celsius under an inert gas atmosphere. Many solids undergo reactions that release gaseous by-products. In TGA, these gaseous by-products are eliminated, and the resulting changes in the remaining sample mass are monitored.

10. Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES)



ICP-OES finds application in quantifying ultra-trace metalsacross various samples, and it's also employed to assess the toxicity of nanoparticles for potential biomedical purposes.

ICP-OES is a method utilized for determining the elemental composition of samples, predominantly those dissolved in water, through the application of plasma and a spectrometer. It finds frequent application in the analysis of trace metals in contaminated water samples. The analytical process involves delivering the solution to be analyzed via a peristaltic pump through a nebulizer into a spray chamber. The resulting aerosol is directed into an argon plasma.

In ICP-OES, the plasma is generated at the end of a quartz torch using a cooled induction coil subjected to high-frequency alternating current. This induces an alternate magnetic field, propelling electrons into a circular trajectory. Ionization occurs through collisions between argon atoms and electrons, establishing a stable plasma. The plasma is exceptionally hot, ranging between 6000 and 18,000 K, with the potential to reach 10,000 K in the induction zone of the torch. Within the torch, processes such as desolvation, atomization, and ionization of the sample transpire.

As a consequence of the thermal energy absorbed by the electrons, they attain a higher excited state. Upon their return to ground level, energy is released in the form of light (photons). Each element exhibits a unique emission spectrum that is captured by a spectrometer. The light intensity at specific wavelengths is measured and, through calibration, translated into concentration values.

Conclusion

Numerous factors affect the quality and quantity of synthesized nanoparticles for their potential applications. So, effective characterization techniques are required to efficiently assess synthesized nanoparticles, enhancing their applicability in environmental, electronic, biomedical, and drug delivery contexts.

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NANO CARBON ANALOGUES, PROPERTIES AND SYNTHESIS

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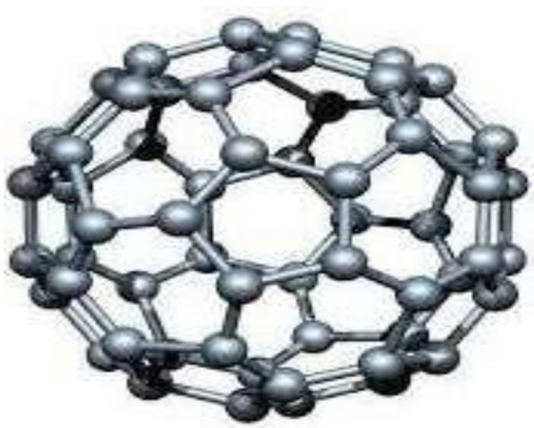
Introduction

Carbon stands as an unparalleled and essential element within our realm, ranking as the sixth most prevalent element in the cosmos, the fourth most abundant in the solar system, and the seventeenth most frequent component in the Earth's crust. Its occurrence is estimated to range from 180 to 270 parts per million, and notably, it claims the position of the second most prevalent element in the human body, trailing only oxygen. Despite its limited presence in the earth's crust, comprising only about 0.2% of the total planetary mass elemental carbon assumes aprofoundly vital role owing to its unique ability to engage in bonding interactions with both lighter elements and its own molecular entities. Prior to the invention of third allotrope of carbonit was believed that carbon exist only in two distinct form that is graphite and diamond. Carbon allotropes are; atomic and diatomic carbon, Graphite and its derivatives, diamond, amorphous carbon, nanocarbon, glassy carbon, carbon nanofoam, carbide derived carbons. Among these allotropes, nano carbon analogues are, fullerenes, carbon nano tubes, carbon nano horns and carbon dots. Carbon-based nanomaterials are a group of nanoparticles made from carbon, which have been studied a lot because of their unique properties. These materials can be altered to perform different function, which makes them interesting for new technologies and solving modern problems. During the modern era, nanotechnology has gained significant focus owing to its immediate potential in creating novel materials endowed with distinctive properties. Numerous attributes, including exceptional directionality, expansive surface area, and remarkable flexibility, render nanostructures highly suitable for a diverse array of applications. This fundamental reason drives the curiosity of researchers from various scientific disciplines towards these materials, given the pivotal roles they have assumed in various emerging technologies. Here we discuss about the historical background, synthesis and properties ofcertain selected nano carbon analogues.

Fullerenes

The identification of a molecule resembling a soccer ball, comprising 60 carbon atoms, emerged somewhat serendipitously during investigations into the composition of matter in outer space. In the course of their inquiry, Donald Huffman and Wolfgang Kratschmer postulated the existence of a molecule resembling a soccer ball, with 60 carbon atoms. However, at that time, no concrete evidence was available. With the help of infrared (IR) spectroscopy and mass spectroscopy, these two scientists subsequently substantiated the presence of this captivating new molecule, consisting 60 carbon atoms intricately bonded into a spherical configuration. The outcomes of this groundbreaking discovery were documented in the journal Nature in 1990. Kroto and Smalley bestowed the term "fullerene" upon the group of molecules detected in the gaseousphase experiments, owing to their likeness to the geodesic domes envisioned by R. Buckminster Fuller. The designation "buckminsterfullerene," commonly referred to as "buckyball," was specifically assigned to the C_{60} molecule, while the broader label "fullerene" encompassed C_n cage molecules constructed from an arrangement of hexagonal and pentagonal facets. They consist of 12 pentagonal and 20 hexagonal facets made up of 60 carbon atoms which are sp2 hybridized and bonded covalently. Buckyballs possess distinctive characteristics including notably elevated superconductivity (33K), icosahedral symmetry, and the ability to form monodisperse nanostructures that can be organized into both film and crystalline arrangements. C_{60} is soluble in benzene, single crystals of it can be grown by slow evaporation from benzene solution, they act as electrophile in chemical reactions, has property of ferromagnetism. 26% volume of face centered cubic fullerene unit cell is empty, doping with alkali atoms like potassium will generate K_3C_{60}. C_{60} is an insulator but when doped with alkali atom it becomes electrically conducting.



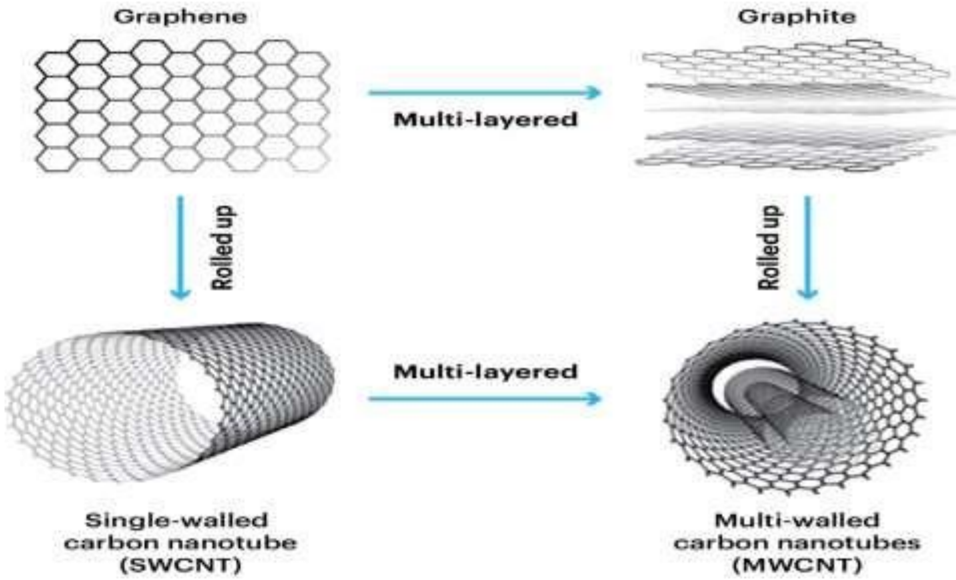
Structure of fullerene

Recently C_{60} is mainly synthesized by arc method in which a spark is generated between pieces of graphite in a chamber filled with helium gas. Later contact arc method was used in which flowof electricity is obtained by a smaller carbon rod touching a bigger fixed carbon rod. The heat generated at the contact point turns the graphite into tiny particles called soot and fullerenes. These particles stick to the walls of a cooled container. A special setup is used where the materials slide against each other. The container is kept in water to stay cool. This method can produce a good amount of C_{60}/C_{70} every day. The soot generated contain about 13% of C_{60}, 2% of C_{70} etc, which is separated by Soxhlet extraction. Typically C_{60} is separated from higher fullerenes by liquid chromatography and the fractions are identified by optical spectroscopy and nuclear magnetic resonance (NMR) spectroscopy data, which can also provide indication on purity. Fullerenes can be synthesized through various methods like arc discharge and laser ablation, enabling the exploration of their remarkable properties. Their exceptional stability, diverse electronic properties, and potential applications in fields ranging from nanotechnology and medicine to energy storage underscore their significance in modern science.

Carbon Nanotubes (CNT)

The discovery of fullerenes has shown us exciting things about nano carbon structures and by arranging sp^2 carbon atoms in a specific way, we can create new structures with unique properties. Carbon nanotubes serve as a best example, which was discovered exactly a decade after the discovery of fullerenes. Carbon Nanotube (CNT), also called bucky tubes, was initially found in 1991 accidently, while studying the surfaces of graphite electrodes used in an electricarc discharge. Later, in 1993, Iijima and Ichihashi successfully the synthesised of a single-wall carbon nanotube with a diameter of just 1 nanometer. But, in 1952 Radushkevich and Lukyanovich, two researchers, presented a clear picture of 50 carbon nanotubes in the Journal of Physical Chemistry while working in the Soviet Union. During the biennial 14th Carbon Conference at Pennsylvania State University in 1979, John Abrahamson provided supporting evidence for carbon nanotubes. Carbon nanotubes can be categorized into two main types based on their structures. The first type is single-walled carbon nanotubes (SWCNT), which consist of just one layer of graphite. The second type is multi-walled carbon nanotubes (MWCNT), which have multiple layers of graphite arranged concentrically. A SWCNT have a diameter of 2nm and a length of 100 μm, making it effectively a one-dimensional structure called nanowire. Three different structures based on orientation are possible for SWCNT, armchair, zigzag, chiralstructure. Nanotubes are commonly enclosed at both ends, and at the tube ends, metal particles are often discovered. This provides evidence for the catalytic function of these metal particles in the formation process.

Carbon nanotubes possess a fascinating trait: they can be either metallicor semiconducting, depending on the tube's diameter and chirality. Typically, the synthesis yieldsa blend of tubes, with approximately two-thirds is semiconducting and one-third is metallic. The metallic tubes have an armchair configuration. When in the metallic state, nanotubes exhibit remarkably high conductivity. It is approximated that they can conduct up to a billion amperes per square centimeter. Magnetoresistance is when a material's resistance changes when a magnetic field is applied to it. Carbon nanotubes show this effect at low temperature. Single- walled nanotubes (SWNTs) can have metallic properties, with resistivity ranging from $5.1 \times 10^{-6}$to 1.2×10^{-4} ohm cm. The hexagonal lattice structure of carbon atoms leaves one valence electron free in each unit, contributing to the electrical properties. Multi-walled carbon nanotubes(MWNTs) show diffusive or quasi-ballistic transport properties. CNTs exhibit exceptional strength in the axial direction. Their Young's modulus ranges from 270 to 950 GPa, and tensile strength varies between 11 and 63 GPa. CNTs show flexibility and resistance to breaking when bent, indicating relative softness in the radial direction. This radial elasticity influences mechanical properties, particularly in nanocomposites. CNTs remain intact even under significant deformation. They can withstand bending without fracturing and endure high pressures and shock waves without breaking. Mechanical properties of CNTs are influenced by their diameter. Smaller-diameter tubes can have theoretical Young's modulus values comparable to diamond, while increasing diameter enhances mechanical properties until they approach those of planar graphite. Reported values for Young's modulus range from 320 to 1470 GPa.

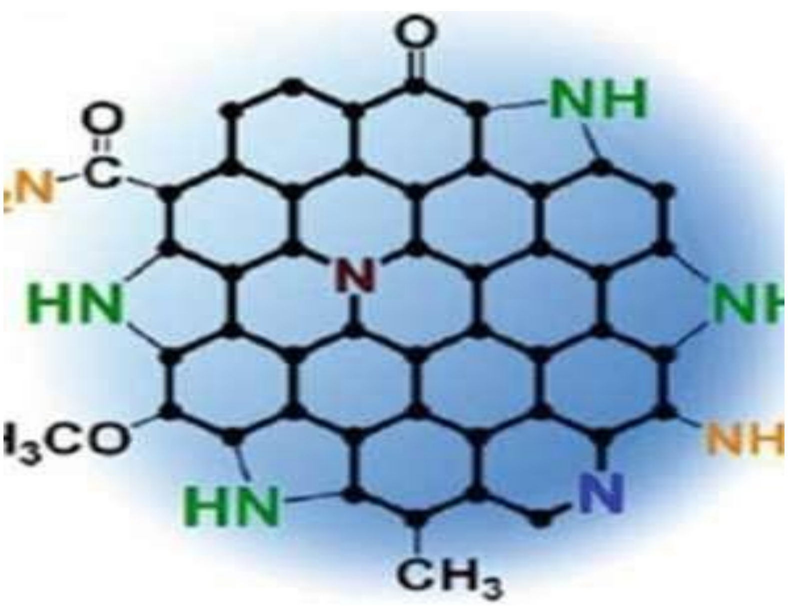


Graphical representation of SWCNT and MWCNT

CNTs can be synthesized mainly through 3 methods, arc discharge, laser ablation and chemical vapour deposition. The arc discharge method involves heating carbon atoms to high temperatures until they become plasma. This happens in a specific pressure range with inert gas. An electric arc forms between close graphite electrodes. This creates carbon plasma at temperatures above 3000 degrees Celsius. To make better carbon nanotubes (CNTs), more research is needed on how the plasma technique works. This method produces flexible CNTs with fewer defects. A mix of gases including argon, helium, nitrogen, carbon, cobalt, and nickel is used for this. Scientists have studied the properties of this plasma at different temperatures. These studies provideinsights for future CNT synthesis using plasma techniques. Laser ablation works like arc discharge but uses a laser to heat carbon. This vaporizes the carbon, and it condenses with a gas stream. A study looked at laser types for making SWCNTs. Laser strength affects SWCNT growth. UV laser has a narrower effective range than infrared. Changing laser fluence results in varied SWCNT diameters. A large amount of CNTs can be made at normal temperature and pressure using pulsed laser on graphite in metal nano-sol. Metal nano-sol acts as a catalyst in thisprocess. CVD for CNT synthesis needs a metal catalyst, often cobalt, nickel, copper, or iron. Chemical deposition is cost-effective, high-yield, and controllable. Some say CVD-made CNTs aren't as good as arc or laser ones. The catalyst helps split hydrocarbons into carbon andhydrogen at lower temperatures. Researchers, like Chen, used nano-MgNi to make MWCNTs via pyrolysis of CH_4 gas. They optimized the reaction for methane conversion and carbon yield in CVD. Their unique properties, along with one-dimensional nature, hold promise for transformative applications in fields such as electronics, materials science, and nanotechnology.

Nano Carbon dots (CDs)

Fluorescent carbon dots were serendipitously discovered during the surface passivation of carbon nanotubes by Xu.et.al in 2004. This finding resulted from observing enhanced luminescence due to surface defects and dispersion efforts. The breakthrough occurred when a fast-moving fluorescent band with color-changing properties under UV light was accidentally observed during the electrophoretic purification of single-walled nanotubes. Analytical characterization revealed the composition: C 53.93%, H 2.56%, N 1.20%, and O 40.33%, composed mainly of carboxyl groups and entirely devoid of metals. C-dots are typically smaller than 10 nm in size. They possess abundant oxygen-containing groups, including sp3 carbon and hydroxyl-attached carbon groups. The interlayer spacing of C-dots measures 0.42 nm, exceeding the 0.33 nm of graphitic interlayer spacing. This suggests a lower degree of crystallinity compared to graphite. Different starting materials yield C-dots with varying structures, ranging from graphitic toamorphous. Non-toxicity and high biocompatibility, water solubility, an adjustable luminous range, high photo stability, an absence of light flicker, easy functionality, rich sources of cheap raw materials, easy large-scale synthesis, have resistance to photo bleaching etc. are the unique properties of CDs. Method of CDs synthesis can be divided into two categories top down and bottom up. In top- down approach, larger carbon precursors are broken down into smaller CDs bymethods like arc discharge, laser ablation, electrochemical oxidation, and so on. Commonly usedcarbon precursors are graphite, carbon nanotubes, carbon black, activated carbon and graphene oxide, etc. Summary of different synthetic methods given in table 1.



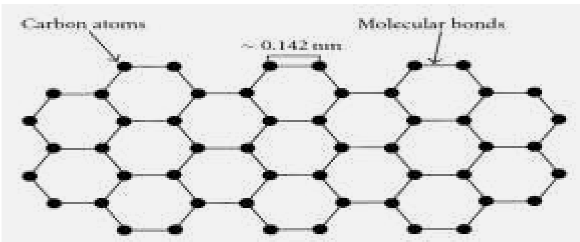
Hypothetical structure of Carbon nano dots

Table 1: summary of different methods synthesis of CDs

Method of synthesis	**advantages**	**disadvantages**	**remarks**
Arc Discharge	Small particle sizes	Complex composition and impurities	Intrinsic fluorescence, no surface modifications needed
Laser Ablation	Successful multi-photon imaging	Yields non-fluorescent carbon nanoparticles (CNPs)	Generates fluorescent CDs from carbon nanoparticles
Electrolysis	Water-soluble CDs from carbonaceous materials	Variable particle sizes	Achieved using different electrode setups
Combustion	Uses readily available raw materials	Requires oxidative acid treatment	Higher dispersibility in CDs
Template Method	Controlled synthesis process	Difficulty in template separation	Potential for uniform particle size
Pyrolysis	High PL quantum yield	Formation and separation challenges	Large-scale CDs obtained via oxidation of carbon precursors
Microwave Synthesis	Novel, green, and efficient	Non-uniform particle size distribution	Rapid synthesis within minutes
Hydrothermal/Solvothermal	High PL quantum yield in one step	Non-uniform CD size, impurities	Simple and controllable reaction

Facile synthesis techniques and remarkable properties of carbon dots have the potential to revolutionize diverse fields ranging from electronics and photonics to biomedicine and environmental remediation.

The groundbreaking discovery of graphene earned Andre Geim and Konstantin Novoselov the Nobel Prize in Physics in 2010. This serendipitous isolation of graphene using adhesive tape and its subsequent exploration ignited a wave of research and innovation across various industries. Graphene, a monolayer of carbon atoms arranged in a 2D honeycomb lattice with a C-C bond length of 0.142 nm, exhibits remarkable properties: high electron mobility of 250,000 cm^2/Vs, impressive thermal conductivity of 5000 W/m-K, and an exceptional Young's modulus of 1 TPa. Graphene serves as the fundamental building block for other carbon materials; stacked graphene forms graphite, while rolled-up sheets create carbon nanotubes. The quality of graphene significantly affects its electronic and optical attributes, necessitating high-quality, single-crystalline graphene for optimal performance in electronic applications. Different methods of graphene synthesis is summarized in table 2 given below.



Schematic representation of graphene sheet

Table: summary of different methods synthesis of graphene

Method of synthesis	**Advantages**	**Disadvantages**	**Product quality type yield**
Exfoliation	Initial method. Simple setup and equipment. Low cost method	Labor-intensive process Prone to structural defects and impurities	Developed by Nobel laureates Andre Geim and Konstantin Novoselov Yields monolayer graphene, but quality can be compromised Presence of defects affects electrical conductivity
Scotch Tape Method	Facilitates large-scale graphene production Easily accessible materials	Requires repetitive peeling Quality control is challenging	Effective for obtaining monolayer graphene structural defects observed through Raman spectroscopy Graphene structure not fully restored after thermal reduction
NMP Exfoliation	Potential for defect-free monolayer graphene	High cost and boiling point of solvent	Not recommended due to solvent expense
Fe-Assisted GNS Production	Eco-friendly alternative to toxic reducing agents	Method may have specific requirements	Utilizes Fe as a reducing agent toobtain GNS Avoids the use of poisonous gases. Like hydrazine and hydroquinone

Chemical Conversion of Graphite to GO	Economical alternative to graphene synthesis. Hydrophilic nature aids exfoliation	Oxygenation disrupts electronic structure. O behaves as an insulating material	Promising method due to cost-effectiveness. Chemical reduction could partially restore conductivity
Hummers Method for GO Synthesis	Established method for GO production	thicker GO films compared to pristine graphene	Utilizes oxidants like H2SO4, HNO3, and KMnO4. Involves oxidation of graphite
Thermal Reduction of GO	Removal of oxide functional groups	Loss of mass and structural defects	Heat treatment reduces rGO's functional groups. Dubin et al.'s low-temperature approach

Graphene a 2D wonder exhibits extraordinary properties, which enable it to open up an array of promising applications, from flexible electronics to advanced coatings and energy storage devices. With the ongoing innovations and collaborations across disciplines, graphene's journey from the laboratory to real-world applications is destined to reshape industries and enrich our technological landscape, driving us toward a more sustainable and interconnected future.

Conclusion

In the realm of nanocarbon analogues, the synthesis and properties of fullerenes, carbon nanotubes, carbon dots, and graphene have unveiled a universe of possibilities. These remarkablematerials, born from the world of nanotechnology, have displayed unparalleled properties that are reshaping industries and scientific frontiers alike. With fullerenes' unique molecular structure, carbon nanotubes' exceptional strength and conductivity, carbon dots' versatile luminescence, and graphene's two-dimensional wonder, the potential for innovation across fields such as electronics, materials, medicine, and energy is boundless. As we embrace the future, the ongoing exploration of these nano carbon analogues promises to usher in an era of unprecedented advancements, offering solutions to complex challenges and pushing the boundaries of what is achievable on the nanoscale.

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APPLICATIONS OF NANO CARBON ANALOGUES

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Introduction

Among these breakthroughs, the applications of nano carbon analogues stand out as a pivotal and burgeoning field. Nanocarbon analogues, including materials such as graphene, carbon nanotubes, and fullerenes, exhibit extraordinary properties at the nanoscale, offering an array of innovative applications across industries. These remarkable materials hold immense potential to revolutionize fields ranging from electronics and energy to medicine and materials engineering. In this exploration, we delve into the multifaceted applications that harness the unique attributes of nano carbon analogues, shaping the landscape of modern technology and scientific progress.

Applications of Fullerenes

1. Organic Photovoltaics (OPV)

Fullerene has a role in organic photovoltaics, where it helps make efficient solar cells. In the best-performing solar cells using a mix of materials, fullerene is used as n-type semiconductors, that accept electrons. It is used along with p-type semiconductors that are electron donors, often a substance like polythiophene. These materials are mixed together to form the active layer of the solar cell, and this mixture is called a bulk heterojunction. Fullerenes are either used directly or modified to make them dissolve more easily. The main derivative used in solar cells isC60, but C70 has been found to be 25% more efficient. Other derivatives like C60 PCBB can increase efficiency by over 40% compared to C60 PCBM. A record efficiency of 4.4% was achieved in 2005 using a fullerene derivative, highlighting how the active layer's properties impact performance. Fullerenes are the preferred n-type material, making up to 75% of the activelayer's weight. Solar cell efficiency is consistently rising, hinting at potential commercial use soon. Polymer transistors, like Organic Field Effect Transistors (OFETs) and photodetectors, are performing better, partly due to the interaction between OFETs and OPVs (organic photovoltaics). The top OFETs use fullerenes like C60, C70, and C84 as n-type semiconductors. Among these, C84-based fullerene OFETs have higher mobility and stability compared to C60 and C70. While more research is required, the realm of polymer electronics is expanding for bothfullerenes and single-walled carbon nanotubes, displaying promising advancements.

2. Antioxidants and Biopharmaceuticals

Fullerenes act as potent antioxidants, rapidly reacting with harmful free radicals that often cause cell damage. They hold significant potential for health, personal care, and various non-physiological applications where preventing oxidative damage is crucial. Major pharmaceutical companies are investigating fullerenes for controlling neurological damage in diseases like Alzheimer's and ALS. They are also being developed for atherosclerosis, photodynamic therapy, and anti-viral treatments. Fullerenes are exceptional at neutralizing free radicals, outperforming even Vitamin E by 100 times. They dissolve well in almond oil, making them suitable for ocular tissue toxicity testing without adverse effects.

3. Additives

As Polymer Additives

Fullerenes and fullerenic black display chemical reactivity and can be incorporated into polymer frameworks, resulting in novel copolymers possessing distinct physical and mechanical attributes. Additionally, they can be introduced to form composites. Extensive research has explored the utilization of fullerenes as additives in polymers, aiming to alter physical traits and enhance performance qualities.

As a Catalyst

The fullerene has a strong capacity to receive and transfer hydrogen atoms. This ability enables processes like hydrogenation (adding hydrogen) and hydrodealkylations (removing alkyl groups using hydrogen). Also efficient at facilitating the transformation of methane into more complex hydrocarbons with larger molecular structures. The substance prevents or suppresses the formation of coke (solid carbon deposits) during chemical reactions, which is beneficial for maintaining reaction efficiency and avoiding undesirable byproducts.

4. Water Purification

Fullerenes, due to their structure and electron configuration, can efficiently catalyze the production of singlet oxygen—a highly reactive and powerful oxidizing agent. This singlet oxygen can selectively degrade organic pollutants present in water sources, breaking them down into harmless byproducts through oxidation processes. This innovative approach offers a promising solution for tackling persistent organic pollutants and ensuring cleaner water resources.

5. Biohazard Protection

Fullerenes, especially C60, exhibit notable antioxidant properties. They can scavenge free radicals and reactive oxygen species, which are implicated in various health issues and the deterioration of materials. This property makes fullerenes valuable in protecting against biohazards, including harmful effects caused by exposure to radiation, toxins, and pollutants. When incorporated into protective materials, such as clothing, coatings, or filters, fullerenes can mitigate the damaging effects of biohazards by neutralizing harmful agents and preventing their interaction with biological systems.

6. Automobiles

The use of fullerene black and rubber compounds enhances the strength and resilience of the vehicle's components. It can withstand wear, stress, and environmental factors better than traditional materials, leading to longer-lasting vehicle parts. Heat build-up can be an issue, especially in areas where friction or energy transfer generates excess heat. Fullerens and fullerene black have properties that can dissipate heat efficiently, contributing to better temperature regulation within the vehicle. Vehicles using these compounds may require less energy to operate and travel the same distance compared to vehicles using traditional materials. This can lead to cost savings for vehicle owners and a reduction in fuel consumption.

7. Medical Field

As MRI Contrast agent

Magnetic Resonance Imaging (MRI) is a widely used medical imaging technique that provides detailed images of the internal structures of the body. Contrast agents are substances introduced into the body before an MRI scan to enhance the visibility of certain tissues or organs. These agents alter the magnetic properties of the surrounding tissues, making them more distinguishable in the resulting MRI images. Fullerenes, due to their unique properties, are used as an MRI contrast agent. Fullerenes have high electron spin and nuclear spin relaxation rates, which can lead to enhanced image contrast in MRI scans. Properly designed fullerene-based nanoparticles can exhibit good biocompatibility, reducing the risk of adverse reactions when introduce into the body. Fullerenes can be functionalized with specific molecules that enable them to target particular tissues or cells. This offers the possibility of targeted imaging, and enhances diagnostic accuracy. Some fullerene-based nanoparticles have shown extended circulation time in the bloodstream, allowing for a longer window of time for imaging procedures.

Drug Delivery System

The water-soluble cationic fullerene known as tetra(piperazino) fullerene epoxide (TPFE) has found use in delivering DNA and siRNA precisely to the lungs. Effective treatment for lung-related diseases necessitates targeted delivery of active agents to specific organ locations. However, challenges arise due to the accumulation of micrometer-sized carriers in the lungs, potentially causing embolization and inflammation. To address this, size-controlled carrier vehicles have been created utilizing TPFE. In the bloodstream, TPFE and siRNA aggregate with plasma proteins, forming micrometer-sized particles. These particles block lung capillaries,releasing siRNA into lung cells. Once siRNA delivery is achieved, the particles swiftly exit the lungs.

Applications Of Carbon Nanotubes (Cnt)

1. Field Emission

Electron field emission materials for technological applications like displays, electron microscopes, and microwave amplifiers. For effective use, these materials need low-emission threshold fields and high stability at high current densities. Carbon nanotubes (CNTs) have proven promising due to their small size, structural integrity, conductivity, and stability. CNTs possess lower threshold fields compared to conventional emitters, with Single-Walled Nanotubes(SWNTs) offering higher current density and longer lifetimes. SWNTs have shown stable emission at substantial current densities, making them appealing for applications such as microwave amplifiers. However, the emission site density of CNTs remains a challenge for high-resolution displays.

1.1 Cathode Ray Lighting Element

The creation of cathode ray lighting elements utilizing carbon nanotubes (CNTs) as field emitters has been pioneered by the Japanese company Ise Electronic Co. These elements adopt a triode-type design, where nanotubes are screen-printed onto metal plates. To enhance color production, a phosphor screen is incorporated onto the inner surface of a glass plate. The resulting phosphor screens exhibit higher luminance compared to traditional thermionic Cathode Ray Tube (CRT) lighting elements, leading to improvements in lighting intensity and efficiency.

1.2 Flat Panel Display

Innovative matrix-addressable diode flat panel displays have been developed, leveraging carbon nanotubes as electron emitters. An example from Northwestern University features nanotube-epoxy stripes on the cathode glass plate and phosphor-coated Indium-Tin-Oxide (ITO) stripes on the anode plate. Pixels are formed at the intersections of cathode and anode stripes. Samsung has also introduced a 4.5-inch diode-type field emission display, incorporating single-walled nanotube (SWNT) stripes on the cathode and phosphor-coated ITO stripes on the anode, arranged perpendicular to the cathode stripes.

1.3 Gas Discharge Tubes in Telecom Network

Gas discharge tube protectors, using noble gas-filled ceramic cases with parallel electrodes, are an established method to guard circuits against transient over-voltages. These protectors create plasma breakdown during high voltages, short-circuiting the system and shielding components from damage. They are used in telecom network devices for lightning and power faults. New prototype protectors employ carbon nanotube-coated electrodes, offering better reliability and performance. The nanotube-based protectors exhibit improved breakdown voltage stability and lower breakdown voltage compared to commercial products, making them attractive for advanced telecom networks like ADSL.

2. Energy Storage

Carbon nanotubes are under investigation for their potential in energy generation and storage. Their unique attributes include compact dimensions, a smooth surface structure, and precise surface specificity, as their structure exposes only the basal graphite planes.

2.1 Electrochemical Intercalation of Carbon Nanotubes with Lithium

Rechargeable lithium batteries operate via the electrochemical intercalation and de-intercalation of lithium between two electrodes. Leading lithium batteries use transition metal oxides for cathodes and carbon materials for anodes, aiming for high-energy capacity, rapid charging, and extended cycle life. Carbon nanotubes (CNTs) have raised speculation about their potential for achieving higher lithium (Li) capacity by fully utilizing all interstitial sites within their structure. The exact Li ion positions in intercalated SWNTs remain uncertain, but it's suggested they occupy interstitial sites between SWNTs. The potential of CNTs as battery electrodes, marked byhigh capacity and performance under high current rates, merits further investigation, although the observed voltage hysteresis needs addressing.

2.2 Hydrogen Storage

CNTs possess a high surface area, along with the ability to adsorb hydrogen molecules onto their surfaces. This property makes them potential candidates for compact and efficient hydrogen storage systems, which are crucial for various applications like fuel cells and clean energy technologies. The adsorption of hydrogen onto CNTs can occur through physisorption, where hydrogen molecules adhere to the CNT surface due to van der Waals forces. This adsorption process is reversible and can occur at relatively low temperatures and pressures, making it suitable for practical applications. Functionalization and doping of CNTs can potentially increasetheir hydrogen storage capacity and improve adsorption kinetics. Achieving high hydrogenstorage capacity while maintaining reversible adsorption-desorption cycles, improving adsorption kinetics, and addressing safety concerns related to hydrogen release are areas of ongoing research.

3. Filled Composite

CNTs can enhance the strength and performance of lightweight materials. They have the potential to be utilized in a variety of products, from sports equipment like tennis rackets to critical components in spacecraft and aircraft. Notably, NASA is investing significantly indeveloping CNT-based composites for futuristic missions, exemplified by their interest in Mars exploration. This indicates the broad range of applications where CNTs are being explored for their ability to contribute to stronger, lighter, and more durable structural materials and filled composites.

4. Nanoprobes And Sensors

The small and uniform dimensions of nanotubes offer diverse applications due to their high conductivity, mechanical strength, and flexibility. Nanotubes hold promise as nanoprobes in various fields, including high-resolution imaging, nano-lithography, nanoelectrodes, drug delivery, sensors, and field emitters. Single multi-walled nanotubes (MWNTs) attached to scanning probe microscope tips enable high-resolution imaging, particularly for deep surface cracks and biological molecules like DNA. While challenges exist in attaching individual

nanotubes to probes, successful growth onto silicon tips using CVD has shown potential for enhancing probe stability and performance.

5. Templates

Carbon nanotubes (CNTs) provide a distinctive avenue for crafting one-dimensional nanostructures by using their narrow, straight channels to host external materials. Initial calculations suggested that capillary forces could confine gases and liquids within CNTs, sparking the concept of producing nanowires. The first practical validation occurred in 1993 when molten lead was solidified within multi-walled nanotubes (MWNTs), generating wires as minute as 1.2nm in diameter. Following this breakthrough, subsequent exploration has encompassed the infusion of CNTs with an array of materials, spanning metals and ceramics, to craft nanowires with assorted structures and compositions.

Application of Carbon Nanodots

1. Bio Sensing

Carbon dots (CDs) exhibit remarkable properties, such as water solubility, customizable surface modifications, non-toxicity, and multicolor fluorescence. These features make CDs versatile candidates for bio-sensing applications. They have been utilized to detect various analytes like glucose, phosphate, pH, metal ions, DNA, proteins, enzymes, and pathogens due to their excellent biocompatibility, cell permeability, and photo stability. For instance, researchers have developed fluorescent boronic acid-modified CDs for non-enzymatic blood glucose sensing. Glucose-induced covalent bonding between CDs and glucose molecules led to selective fluorescence quenching, enabling the detection of glucose in human serum. Fluorescence resonance energy transfer-based sensors have been designed for detecting substances like H2S and H2O2 in water samples, serum, and living cells. These sensors utilize the structural and spectral changes in CDs upon interaction with the target analytes, offering high sensitivity, selectivity, and cell permeability.

2. Bio Imaging

Favorable optical characteristics, chemical stability, and biocompatibility of CDs offer an appealing alternative to semiconductor quantum dots (QDs) and organic dyes. Notably, CDs are non-toxic and biocompatible, making them desirable for visualizing biological systems. In the realm of in vitro bio imaging, CDs have demonstrated significant potential. A study by Cao et al. employed surface-passivated CDs synthesized through laser ablation for cellular imaging. The water-soluble CDs exhibited strong fluorescence under various excitation conditions and were effectively used to label cell membranes and cytoplasm. Functionalized CDs have been explored for disease diagnosis and drug targeting, with transferrin-modified CDs showing enhanced targeting to tumor cells. Their biocompatibility and low toxicity suggest CDs could serve as valuable contrast agents for in vivo applications, such as ZnS-doped CDs after being passivated with PEG1500N.

3. Environmental Monitoring

Their key advantages include high biocompatibility, adjustable fluorescence properties, substantial two-photon absorption capabilities, remarkable photostability, simple functionalization, cost-effectiveness, and scalable production. These attributes make CDs highly valuable for a range of applications, enabling the detection of various substances like Hg2+, Cu2+, Fe3+, Ag+, Pb2+, Sn2+, Cr(VI), and more through monitoring changes in their fluorescence intensity in response to external stimuli.

3.1 Cation detection

Divalent mercury ions (Hg2+), is crucial due to their high toxicity and potential harm to human health. Carbon dots (CDs) have shown promise in addressing this concern. Various studies have demonstrated their effectiveness in detecting Hg2+ ions with high sensitivity and selectivity. These efforts include using unmodified CDs, hydrothermally synthesized CNPs, and functionalized CDs, all achieving impressive detection limits, making CDs a promising tool for efficient and accurate Hg2+ ion detection.

3.2 Anion detection

Anion detection using carbon dots (CDs) has been explored in various studies. CDs have been utilized for detecting nitrite ions through chemiluminescence properties when exposed to peroxynitrous acid. Another approach involves functionalizing CDs with carboxyl groups to detect phosphate ions by leveraging the coordination of Eu3+ ions. Similarly, a fluorescent probefor fluoride ions (F-) detection was designed based on competitive ligand reactions between carboxylate groups on CDs and F- ions coordinated to Zr(H2O)2EDTA. CDs have also been applied for the detection of sulfide ions, where their electrochemical luminescence properties were used to create a rapid and selective sensor.

4. Food Quality Control

Food safety is crucial for human health, and recent years have seen growing concerns due to various food safety issues. To ensure food safety, accurate methods are needed to detect harmful substances in food. Tartrazine, a synthetic pigment used in foods, has raised health concerns, leading to the development of techniques to detect it, such as using fluorescent carbon dots (CDs) synthesized from aloe. CDs have also been employed to detect cysteine and Fe3+ ions through fluorescence quenching and recovery, glucose by quenching via hydrogen peroxide, and phytic acid through photoinduced electron transfer. Additionally, CDs have been utilized in a fluorescence resonance energy transfer sensor to determine vitamin B12 concentrations effectively.

5. Explosive Screening

They offer a green alternative to quantum dots (QDs) and have gained traction in trace explosive detection. TNT, a worrisome environmental pollutant, prompted researchers to develop efficient platforms for detecting ultra-trace levels of TNT. N-rich CDs were synthesized and employed forboth fluorescence and electrochemical detection of TNT, with impressive sensitivity and a linear range. Similarly, a fluorescence sensor using CDs capped by molecularly imprinted polymers showed selectivity and sensitivity for TNT detection, proving effective for real sample analysis. In the case of picric acid (TNP), CDs doped with rare earths and amorphous photoluminescent CDs were devised as selective and sensitive methods for detecting TNP, aiding in environmental and security applications.

Application of Graphene

Graphene holds promise in various applications, such as single-molecule gas sensing, biomedical devices, and optoelectronic devices.

1. Energy Storage

Lithium-ion batteries (LIBs) are favored for energy storage due to their extended cycle life, higher specific energy, and rechargeable nature, with graphene's outstanding properties like electrical conductivity, surface area, and stability making it a suitable energy storage material. However, conventional electrode materials like SnO_2, CO_3O_4, and others face limitations in practical use due to low electrical conductivity. Incorporating graphene-based materials has shown potential for enhancing capacity and cyclic performance. Graphene-enhanced materials, such as graphene-encapsulated CO_3O_4, Mn_3O_4, and Fe_3O_4, have demonstrated improved energy density, current density, and chemical stability in LIBs. Supercapacitors also benefit from graphene's high specific area, as demonstrated in graphene-hydrated RuO2 and nitrogen-doped graphene-based composites for enhanced capacitance and stability in supercapacitor applications. Additionally, graphene-modified materials have shown promise in thermal energy storage, with increased thermal conductivity observed in palmitic acid/GO composites.

2. Energy Conversion

Fuel cells offer high conversion efficiency and ease of use, with graphene replacing CNTs as a promising material for enhanced catalytic activities. Commonly, expensive materials like Pt, Au, and Ru are used for the cathode in fuel cells, with Pt being widely utilized despite its high cost and susceptibility to CO poisoning. Efforts to develop metal-free oxygen reduction reaction (ORR) catalysts led to the synthesis of Pt/graphene hybrids, such as PtNP/GNS composites, Pt- deposited GNS, and functionalized graphene sheets, which exhibited improved current density and ORR activity compared to conventional Pt-based catalysts. Doping and intercalation, like B and N doping and rGO/CNT hybrids, further enhanced the performance of graphene-based hybrid catalysts in fuel cells.

3. Graphene Based Conductors

Graphene exhibits remarkable electrical conductivity, surpassing copper due to its dual charge carrier behavior involving both electrons and holes. Research by Ivan et al. introduced graphene-based transparent conductors by intercalating few-layer graphene (FLG) with FeCl3, leading to a low sheet resistance of 8.8 Ω/sq, considerably below critical values for multi-layer and chemically derived graphene. Additionally, studies by Sajid et al. explore the application of graphene-based conductors as transmission lines, showing wave propagation characteristics akin to microstrip transmission lines and potential for planar antenna arrays.

Conclusion

As we conclude this exploration, it is evident that these nano carbon analogues have transcended traditional material limitations, ushering in a new era of innovation and discovery. Fullerenes, with their unique hollow structures and exceptional properties, have showcased potential in fields as diverse as drug delivery, electronics, and even energy storage. Carbon nanotubes, with their remarkable strength, electrical conductivity, and flexibility, have proven their worth in reinforcing materials, creating high-performance electronics, and revolutionizing medical applications. Carbon dots, the smallest of the nano carbon analogues, have emerged as versatile luminous nanoparticles with potential applications in imaging, sensing, and even disease diagnosis. And last but certainly not least, graphene, the two-dimensional wonder material, has disrupted numerous industries, enabling breakthroughs in electronics, energy storage, and composite materials. As these nano carbon analogues continue to be refined, explored, and integrated into various domains, the future holds the promise of more groundbreaking discoveries and practical applications. Their ability to transform conventional materials and reshape industries underscores the profound impact of nanotechnology on our modern world.The journey from laboratories to real-world applications has only just begun, and the tale of fullerene, carbon nanotubes, carbon dots, and graphene promises to be one of the most captivating chapters in the ongoing narrative of scientific progress.

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NANO BIOPOLYMERS: SYNTHESIS AND CHARACTERIZATION

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Introduction

Biopolymers are natural polymers produced by living organisms. These compounds, including proteins, nucleic acids, and polysaccharides, are fundamental to life processes. They offer biocompatibility, low toxicity, and diverse functionalities. Biopolymers have been used extensively in medical, environmental, and industrial applications due to their renewable nature and compatibility with living systems.

Nano Biopolymers

Nano biopolymers are materials that combine the properties of both nanomaterials and biopolymers. Nanomaterials are materials that have at least one dimension in the nanometer scale (1-100 nanometers). At this scale, materials can exhibit unique properties due to their small size and high surface area-to-volume ratio. Nano biopolymers are created by incorporating nanomaterials into biopolymers or by modifying biopolymers at the nanoscale level. This combination of nanotechnology and biopolymers can lead to materials with novel properties and potential applications in various fields, including medicine, agriculture, and materials science. Nano biopolymers exhibit improved mechanical, chemical, and biological attributes, makingthem suitable for targeted applications such as drug delivery, tissue engineering, and diagnostics. Biopolymers provide a natural and compatible framework, reducing adverse reactions when introduced into living organisms. This is crucial for medical implants, drug carriers, and regenerative therapies. Nano biopolymers can encapsulate drugs, nutrients, or therapeutic agents, enabling controlled release over time. This feature is invaluable in medicine for personalized treatments. Many nano biopolymers are derived from renewable sources, aligning with the push for sustainable materials in various industries. These materials can be engineered to possess multiple functions simultaneously, such as targeting specific cells, sensing biomolecules, and interacting with tissues.

Nano Biopolymers and Their Nanoscale Effects

The enhanced properties of nano biopolymers are a direct consequence of their nanoscale structure and composition. These properties arise from factors such as increased surface area, quantum effects, size-dependent properties, tailored surface chemistry, enhanced bioavailability, improved biocompatibility, and targeted delivery. These effects have broad applications in fields like medicine, materials science, and environmental solutions, making nano biopolymers a versatile tool for addressing diverse challenges. Their unique combination of biologically derived components and nanoscale effects offer a platform for designing advanced materials withtailored properties to address a wide array of challenges.

Sources of Biopolymers

Nano biopolymers can be sourced from various origins, including marine sources, plant sources, and animal sources. Each source provides a diverse range of biopolymers that can be harnessed and engineered at the nanoscale for different applications. Each source provides distinct biopolymers with unique properties, making it possible to tailor materials for specific applications.

Plant Sources:

- Starch: Derived from crops like corn, potatoes, and rice, starch can be processed into nanoparticles for use in food packaging, drug delivery, and biodegradable materials.
- Cellulose: Found in plant cell walls, cellulose can be used to create nanocellulose materials with applications in packaging, textiles, and biomedical materials.
- Pectin: Obtained from fruits, pectin can form nanoparticles for drug delivery and encapsulation of bioactive compounds.
- Alginate: Obtained from brown seaweeds, alginate is used in drug delivery, wound dressings, and tissue engineering. It can form hydrogels and nanoparticles for controlled release of therapeutic agents.
- Carrageenan: Extracted from red seaweeds, carrageenan is used in food additives, drug delivery systems, and cosmetics. It can form gels and nanoparticles with various applications.

Animal Sources:

- Collagen: Derived from animal connective tissues, collagen is used in wound healing, tissue engineering, and cosmetic formulations due to its biocompatibility and support for cell growth.
- Gelatin: Derived from collagen, gelatin can be processed into nanoparticles for drug delivery and wound healing applications.
- Chitin: Chitin is derived from the shells of crustaceans like shrimp and crabs. Chitosan, the deacetylated form of chitin, is widely used in wound healing, drug delivery, and tissue engineering due to its biocompatibility and antimicrobial properties.
- Silk Fibroin: Obtained from silk-producing insects, silk fibroin is used in tissue engineering scaffolds, drug delivery, and wound dressings due to its biocompatibility and mechanical properties.

Marine Biopolymers

Biopolymers sourced from marine environments represent some of the most prevalent naturally occurring polymers found in all living organisms. The primary origins of marine biopolymers are marine algae, fishes, and crustaceans. Seaweeds yield natural biopolymers such as fucoidan, alginate, carrageenan, and porphyran. From marine crustaceans, chitosan and chitin oligosaccharides (COS) are extracted as natural biopolymers. Natural polymers like collagen and hydroxyapatite, with storage and structural functions, are also derived from marine sources. These marine biopolymers possess qualities such as renewability, stability, cost-effectiveness, abundance, biocompatibility, biodegradability, and non-toxicity. Over recent years, biopolymers have found widespread application in various fields, including cosmeceuticals, nutraceuticals, and pharmaceuticals.

Seaweed Based Nanomaterials

Seaweeds (macroalgae) forms a rich reservoir of biopolymers such as fucoidan, alginate, carrageenan etc.

Fucoidan Based Nanomaterials

Derived from brown seaweeds, fucoidan stands out as a natural biopolymer. Its polysaccharide backbone features sulfate ester groups, contributing to its notable high negative charge. Employed as a coating material for nanoparticles (NPs), fucoidan exhibits biocompatibility and biodegradability. Beyond its role as a coating material, fucoidan has found application as an immune-therapeutic functional polymer, positioning it as a promising drug candidate for pharmaceutical purposes. This uniqueness arises from sulfate ester groups on its polysaccharide backbone, rendering it highly negatively charged. Fucoidan serves as a coating material for nanoparticles (NPs) due to its biocompatible and biodegradable nature. Its potential goes beyond mere coating, as it has been explored for immune-therapeutic functions and pharmaceutical applications. Researchers have investigated fucoidan-based nanoparticles for combined immune-chemotherapy, capping agent for environmentally friendly gold nanoparticle synthesis, drug delivery and imaging by loaded with the drug doxorubicin, for making silver nanoparticles using fucoidan, fabrication of liposome-encased fucoidan nanoparticles for anti-osteosarcoma effects etc.

Alginate Based Nanomaterials

Alginate, a linear anionic biopolymer sourced from marine brown algae, is recognized for its natural composition. Exhibiting characteristics such as water solubility, biocompatibility, biodegradability, and mucoadhesiveness, alginate has become instrumental in various pharmaceutical and biomedical applications, particularly in the development of controlled release devices. Notably, alginate nanoparticles (NPs) have shown significant potential for biomedical purposes, such as drug delivery, owing to their ability to efficiently encapsulate highly effective drugs, proteins, and peptides. A distinct advantage of alginate NPs lies in their tendency not to agglomerate within organs during the delivery of drugs or proteins.

Researchers have recently made significant strides in utilizing alginate-based nanoparticles for advanced cancer therapies. These specialized nanoparticles are designed to carry a potent anticancer drug, DOX, and are modified with glycyrrhetinic acid to enhance their targeting capabilities towards liver cancer cells. Additionally, a complex form of these nanoparticles, known as GA-ALG/DOX-ALG NPs, has been developed. These nanoparticles are not only sensitive to changes in pH, but they also exhibit a remarkable ability to specifically target liver tissues. In fact, these GA-ALG/DOX-ALG NPs have shown exceptional antitumor effects, achieving a remarkable 78.91% inhibition of tumor growth. This discovery suggests that GA-ALA/DOX-ALG NPs hold significant promise as a potential therapeutic approach for treating liver cancer.

Carrageenan Based Nanomaterials

In recent times, the use of natural biopolymers in crafting biocompatible metal nanoparticles has garnered increased attention, especially due to their versatile applications in the biomedical field. Among these biopolymers, carrageenan, derived from red seaweeds, has emerged as a noteworthy candidate. Carrageenans exhibit qualities like water solubility, biocompatibility, biodegradability, and non-toxicity, making them suitable as nanoparticles (NPs) for various biomedical applications. The focus has particularly turned towards carrageenan-chitosan NPs for drug delivery, employing a mild and convenient polyelectrolyte method for their production. This approach enables the formation of NPs in an aqueous environment under gentle conditions, avoiding the use of harsh organic solvents or aggressive processes. Consequently, chitosan-carrageenan NPs find potential applications not only in drug delivery but also in areas like tissue engineering and regenerative medicine.

The synthesis of silver nanoparticles (AgNPs) in a k-carrageenan solution can be achieved through a sonochemical method. Additionally, a bio nanocomposite film, composed of carrageenan, clay mineral, and AgNPs, was prepared and exhibited antimicrobial activity against both Gram-positive and Gram-negative bacteria. Polyelectrolyte complexation facilitated the preparation of chitosan/carrageenan NPs, characterized by their small size and high positive surface charge, making them promising tools for applications in mucosal delivery of macromolecules.

Chitin and Nano Derivatives

Chitin and nano chitin are biopolymers derived from natural sources that have gained attention for their versatile properties and potential applications in various fields. Chitin is a natural polymer found in the shells of crustaceans, insects, and the cell walls of fungi. When chitin is processed into nanoscale particles or modified at the nanoscale, it becomes nano chitin, which exhibits enhanced properties due to its small size and increased surface area. It is a polysaccharide composed of N-acetylglucosamine units linked together. It is abundant in nature and has several noteworthy applications.

- Medical Applications: Chitin and its derivatives have been used in wound dressings, tissue engineering scaffolds, and drug delivery due to their biocompatibility and potential to stimulate tissue regeneration.
- Agriculture: Chitin-based materials are used as natural pesticides, as they can inhibit the growth of pests and pathogens. Chitin also has applications in improving plant growth and nutrient

absorption. Water Treatment: Chitin can be used for water purification, as it has the ability to adsorb heavy metals and other contaminants from water.

- Food Industry: Chitin and chitosan, a derivative of chitin, are used in food packaging materials due to their antimicrobial properties. Chitosan-coated films can help extend the shelflife of perishable foods.

- Nano chitin is produced by breaking down chitin into nanoscale particles or modifying its structure at the nanoscale. These nanoparticles offer additional properties and applications:

- Biomedical Applications: Nano chitin can be used in drug delivery systems, wound dressings, and tissue engineering scaffolds, taking advantage of its improved surface area and interactions with cells. Cosmetics: Nano chitin can be incorporated into cosmetic formulationsto enhance the texture and stability of products, providing benefits to skincare and hair care products.

- Biodegradable Materials: Nano chitin-based materials can be used in the development of biodegradable plastics and other environmentally friendly materials.

- Nanostructured Films: Nano chitin can be incorporated into thin films with enhanced mechanical and barrier properties, making them useful in various applications such as food packaging.

- Biomedical Imaging: Nano chitin particles can be modified for use in medical imaging and diagnostics.

Chitin oligosaccharides (COS) represent depolymerization products of chitosan with a low molecular weight, and they have garnered attention in the biomedical domain due to their water-solubility, abundance, cost-effectiveness, biocompatibility, biodegradability, and non-toxic nature. Recently, researchers have directed their focus towards utilizing chitosan oligosaccharide nanoparticles as innovative carriers for drug and gene delivery. A noteworthy application includes chitosan oligosaccharide-stabilized gold nanoparticles, envisioned as a novel approach for drug delivery and photoacoustic imaging in cancer cells. Additionally, chitosan oligosaccharide-stabilized ferromagnetic iron oxide nanocubes have been identified as nanotherapeutic agents for hyperthermia cancer treatment. Furthermore, chitosan oligosaccharide-modified gold nanorods have been employed for specific targeting and noninvasive imaging purposes.

Marine Collagen and Nano Derivatives

Collagen is a complex protein that is made up of a combination of amino acids, including glycine, proline, and hydroxyproline. Collagen is distributed throughout the body and is an integral structural component of skin, bone, tendon, cartilage, blood vessels etc. As we age, the production of collagen in the body decreases, which can lead to a number of health issues including osteoporosis and osteoarthritis. There are different types of collagen that are used in skincare products, with the most common types being Type I and Type III collagen. Type I collagen is found in the skin, bones, and tendons, while Type III collagen is found in the skin, muscles and blood vessels. Type I and Type III, are the most commonly used collagen types in cosmetic industry due to their abundance in human skin. Collagen can be directly derived from different animal sources, such as bovine, chicken, fish and shellfish.

In recent years, there has been increasing interest in marine collagen, which is derived from fish skin, bone, scales, fins and entrails is said to have a higher bioavailability than collagen derived from terrestrial sources. Moreover, marine collagen is free from the risk of protein misfolding, bovine spongiform encephalopathy, zoonotic and allergenicity. Marine collagen is also rich in amino acids such as glycine, proline and hydroxyproline, which are important building blocks for the formation of collagen in the skin. Apart from finfish, marine sources such as cuttlefish, squid, octopus, sponges and jellyfish have been studied for their collagen content and specific functional and bioactive properties.

Collagen and Nano collagen are both biomaterials with various applications in fields such as medicine, cosmetics, and tissue engineering. Nano collagen is produced by breaking down collagen into nanoscale particles, which can enhance its properties and open up new applications. Nano collagen can be incorporated into tissue scaffolds to mimic the natural extracellular matrix and promote cell adhesion, proliferation, and tissue regeneration. Nano collagen-based dressings can provide enhanced wound healing properties by improving cell migration and tissue repair. Nano collagen particles can be functionalized to encapsulate and deliver drugs with improved targeting and controlled release profiles. It can be used in cosmetic formulations for better skin penetration, increasing the efficacy of active ingredients. Apart from that, Nano collagen can be modified for use in imaging and diagnostics, aiding in visualizing biological structures. Also, it can be combined with other materials to create scaffolds for bone regeneration, helping to repair bone defects and fractures.

Hydroxyapatite And Nanoderivatives

Hydroxyapatite (HA) and nan hydroxyapatite (nHA) are materials that play significant roles in various fields, particularly in medicine, dentistry, and biomaterials. They are forms of calcium phosphate compounds that have unique properties and applications due to their structure and composition. Hydroxyapatite is a naturally occurring mineral that makes up a significant portion of the inorganic component of bones and teeth. Its chemical formula is $Ca_{10}(PO4)_6(OH)_2$, indicating its composition of calcium, phosphate, and hydroxyl ions. Hydroxyapatite is known for its excellent biocompatibility and bioactivity, making it a valuable material in several areas.

Hydroxyapatite is used as a bone substitute in orthopedic and dental applications. It can be used to fill bone defects, promote bone regeneration, and aid in the integration of implants. It is used in dental materials such as toothpaste and dental implants due to its similarity to the mineral component of teeth. It can help remineralize tooth enamel and prevent tooth decay. Hydroxyapatite coatings can be applied to medical implants to improve their integration with surrounding tissues, reduce implant rejection, and promote osseointegration. Hydroxyapatite particles can be used as carriers for drug delivery, allowing controlled release of therapeutic agents. Hydroxyapatite scaffolds provide a supportive structure for tissue regeneration in applications such as bone and cartilage tissue engineering.

Nanohydroxyapatite is hydroxyapatite that has been processed into nanoscale particles, typically ranging from a few nanometers to around 100 nanometers. This nanoscale form ofhydroxyapatite exhibits unique properties due to its small size and high surface area-to-volume ratio. Applications of nanohydroxyapatite include:

- Dental Restoratives: Nanohydroxyapatite is used in dental restoratives and remineralizing agents to repair and strengthen teeth, promoting enamel remineralization.
- Bone Regeneration: Nanohydroxyapatite is incorporated into bone grafts and scaffolds to improve their bioactivity and support the regeneration of bone tissue.
- Drug Delivery: Nanohydroxyapatite particles can be functionalized for targeted drug delivery, offering precise release of therapeutic agents to specific locations.
- Biomedical Imaging: Nanohydroxyapatite can be modified for use in medical imaging, aiding in visualizing tissues and structures.
- Cosmetic Applications: Nanohydroxyapatite is used in cosmetic formulations for skincare products, as it can enhance the appearance and texture of the skin.

Melanin and Nano melanin

Melanin and Nano melanin are both intriguing materials with diverse applications in fields such asbiology, medicine, materials science, and more. Melanin is a natural pigment found in various organisms, including humans, and it plays important roles in coloring skin, hair, eyes, and other tissues.

Melanin is a complex biopolymer that is primarily responsible for the color of skin, hair, and eyes in humans and other animals. It has several functions and applications. Melanin absorbs and scatters ultraviolet (UV) radiation, providing protection against the harmful effects of excessive sun exposure. Melanin helps protect cells from DNA damage caused by UV radiation by absorbing and dissipating the energy as heat. In the eyes, melanin is involved in visual processes by controlling the amount of light that enters the retina. In the auditory system, melanin contributes to sound perception. It is also involved in various biological signaling pathways andprocesses in the body, including wound healing, immune response, and inflammation.

Nano melanin is melanin that has been processed into nanoscale particles or modified at the nanoscale, which can have unique properties and applications due to its small size and increased surface area. This form of melanin can have distinct properties and applications:

- Biomedical Imaging: Nano melanin can be used as a contrast agent for medical imaging techniques like MRI and photoacoustic imaging due to its strong absorption properties.
- Drug Delivery: Nano melanin particles can be engineered to encapsulate and deliver drugs to specific sites in the body, taking advantage of their small size and biocompatibility.

- Photothermal Therapy: Nano melanin can be used in photothermal therapy, where the nanoparticles absorb light energy and convert it into heat, selectively destroying targeted cancer cells.
- Biomedical Sensors: Nano melanin can be functionalized to create sensors for detecting biomolecules, pathogens, or other analytes in biological samples.
- Materials Science: Nano melanin can be incorporated into materials to enhance their properties, such as improving the mechanical strength of composites or providing antioxidant properties.
- Energy Harvesting: Melanin's ability to absorb light can be harnessed for applications in solar energy harvesting and photocatalysis.

Synthesis of Nano biopolymers

Creating Nano biopolymers involves various methods that can be categorized as ‘bottom-up’ ‘top-down’, and ‘modification techniques. These approaches enable precise control over the size, shape, and properties of the resulting Nano biopolymers, opening up opportunities for tailored applications.

1. **Bottom-Up Approaches**: Bottom-up approaches involve assembling Nano biopolymers from smaller building blocks, often at the molecular or nanoparticle level. This method emphasizes self-assembly and molecular interactions.

Self-Assembly: Biopolymers can self-assemble into nanostructures driven by their inherent properties, such as hydrogen bonding or electrostatic interactions. For example, proteins can fold into specific shapes or form nanoscale aggregates.

Molecular Engineering: Chemical modifications can be applied to biopolymers to induce specific interactions that guide self-assembly, resulting in well-defined nanostructures.

2. **Top-Down Approaches**

Top-down approaches involve breaking down larger biopolymer structures into nanoscale components. This method allows for the creation of Nano biopolymers with controlled size and shape.

Mechanical Processes: Techniques such as milling, grinding, and homogenization can reduce biopolymer particles to nanoscale dimensions. Mechanical force is applied to break down larger structures.

Electrospinning: Biopolymer solutions can be electro spun to create nanofibers with controlled diameters. This approach is useful for generating nanofibrous scaffolds in tissue engineering.

3. **Modification Techniques**: Modification techniques involve altering the properties of existing biopolymers through chemical, physical, or biological means to achieve desired nanoscale characteristics.

Chemical Modification: Biopolymers can be chemically modified to introduce functional groups that facilitate self-assembly or interaction with other molecules.

Crosslinking: Crosslinking agents can be used to modify biopolymers, altering their mechanical properties and forming nanoparticle or nanogel structures.

Surface Functionalization: Nano biopolymers' surfaces can be modified with ligands, biomolecules, or nanoparticles to impart specific functionalities for targeted applications.

Properties and Advantages

Nano biopolymers exhibit a range of properties that make them particularly attractive for various applications such as biocompatibility, biodegradability, and specific functionalities etc.

Biocompatibility: Biocompatibility refers to the ability of a material to interact with living systems without causing adverse reactions. Nano biopolymers often possess inherent biocompatibility due to their natural origin, which makes them well-suited for medical and biological applications.

Biocompatible Nano biopolymers offer a range of notable advantages that make them exceptionally valuable in medical applications. One primary advantage is their ability to significantly diminish the risk of immune responses. Due to their innate nature as natural substances, biopolymers are readily recognized by the body, thereby minimizing the potential for adverse reactions such as rejection or inflammation upon introduction. Moreover, these Nano biopolymers excel in promoting improved integration with biological tissues, which is crucial for the success of regenerative therapies and the effectiveness of implants. This enhanced tissue integration capability not only facilitates better functional outcomes but also contributes to the overall long-term success of medical interventions. Furthermore, the utilization of biocompatible Nano biopolymers ensures a heightened safety profile in medical settings. These materials are less likely to induce toxic effects or give rise to prolonged complications, renderingthem well-suited for medical applications where safety and minimal risk are paramount considerations.

Biodegradability: Biodegradability refers to the ability of a material to break down naturally into harmless byproducts over time. Many Nano biopolymers are biodegradable, making them environmentally friendly and suitable for applications where sustainable materials are crucial. Biodegradable Nano biopolymers minimize the accumulation of waste and pollutants, contributing to eco-friendly practices.

Controlled degradation: Biodegradability can be engineered to match specific application timelines, ensuring that the material breaks down when it's no longer needed.

Compatibility with natural systems: Biodegradable Nano biopolymers can be metabolized by living organisms, preventing long-term persistence and potential harm.

Specific Functionalities: Nano biopolymers can be engineered to possess specific functionalities through modifications, making them adaptable for targeted applications. Examples include drug delivery, tissue engineering, and diagnostic imaging. Nano biopolymers can encapsulate drugs, allowing controlled release and targeted delivery to specific cells or tissues. Functionalized Nano biopolymers can have ligands or receptors that interact specifically with certain cell types, improving precision in therapies. Nano biopolymers can incorporate multiple functionalities within a single material, expanding their potential applications and versatility.

Advantages Over Traditional Materials:

Nano biopolymers offer distinct advantages over traditional materials in various applications: Medical Implants: Nano biopolymers' biocompatibility and biodegradability make them superior choices for implants, reducing the risk of adverse reactions and minimizing long-term health concerns.

Nano biopolymers play a crucial role in drug delivery by releasing medicines gradually, improving their effectiveness and minimizing side effects compared to traditional methods.They're also well-suited for tissue engineering, as their similarity to natural tissues and customizable properties make them great for creating scaffolds that help tissues regenerate. In environmental applications, biodegradable Nano biopolymers are valuable, especially for sustainable packaging that reduces pollution and waste.

Applications in Medicine

Nano biopolymers have found a plethora of applications in the field of medicine, where their unique combination of biocompatibility, tunable properties, and targeted functionalities offer innovative solutions to various challenges.

1. **Drug Delivery**: Nano biopolymers serve as excellent carriers for drug delivery due to their ability to encapsulate and release therapeutic agents in a controlled manner. These applications include:

   Targeted Drug Delivery: Functionalized Nano biopolymers can be designed to selectively deliver drugs to specific cells or tissues, minimizing off-target effects and enhancing treatment efficacy.

   Personalized Medicine: Nano biopolymers enable the customization of drug release profiles, allowing tailored treatment plans for individual patients.

2. **Tissue Engineering**: Nano biopolymers provide scaffolds and structures that support tissue regeneration, making them crucial in tissue engineering and regenerative medicine: Scaffold Materials: Nano biopolymers create a biomimetic environment that encourages cell growth, differentiation, and tissue formation. Organ Transplantation: Nano biopolymer-based scaffolds offer potential solutions for growing replacement organs and reducing the need for donor organs.

3. **Wound Healing**: Nano biopolymers contribute to advanced wound healing solutions with their properties for promoting tissue repair and regeneration:

   Wound Dressings: Nano biopolymer-based wound dressings offer improved healing rates, reduced infection risk, and enhanced comfort for patients.

Controlled Release of Therapeutics: Nano biopolymers can deliver growth factors and antimicrobial agents directly to wound sites, accelerating healing.

4. **Medical Imaging**: Nano biopolymers can be functionalized for imaging purposes, enhancing diagnostic accuracy and visualization:

   Contrast Agents: Nano biopolymers can carry contrast agents for imaging modalities like MRI, CT scans, and ultrasound, providing better visualization of tissues and anomalies.

5. **Cancer Therapy**: Nano biopolymers are actively investigated for various cancer treatment strategies:

   Targeted Therapy: Functionalized Nano biopolymers can deliver chemotherapy drugs directly to cancer cells, minimizing damage to healthy tissues.

   Photo thermal Therapy: Nano biopolymer-based nanoparticles can absorb light energy and convert it into heat, selectively destroying cancer cells.

6. **Biosensors and Diagnostics**: Nano biopolymers play a role in developing sensitive and specific biosensors for disease detection and monitoring: Functionalized Nano biopolymers can be used to create biosensors that detect specific biomarkers associated with diseases. Nano biopolymer-based devices enable rapid and cost-effective diagnosis at the point of care.

7. **Gene Delivery**: Nano biopolymers can serve as vectors for delivering genetic material into cells, aiding in gene therapy and genetic engineering .Nano biopolymers protect and deliver therapeutic genes into target cells, potentially correcting genetic disorders or promoting desired cell functions. Nano biopolymers' versatility, biocompatibility, and precise control over properties make them invaluable tools in modern medicine.

Environmental Applications

Nano biopolymers also hold significant promise in environmental applications, where their biodegradability, functional diversity, and eco-friendly nature contribute to solving various environmental challenges.

1. **Water Purification**: Nano biopolymers play a crucial role in improving water quality and ensuring access to clean drinking water

   Heavy Metal Removal: Nano biopolymer-based adsorbents can effectively bind heavy metals, such as lead, mercury, and cadmium, from contaminated water sources.

   Pollutant Filtration: Nano biopolymer membranes can filter out pollutants, organic contaminants, and microorganisms, enhancing water treatment processes.

2. **Biodegradable Materials**: Nano biopolymers provide sustainable alternatives to conventional plastics and materials that contribute to environmental pollution. Nano biopolymer-based packaging materials break down naturally, reducing plastic waste and minimizing harm to

ecosystems. Nano biopolymer-based disposable items decompose more rapidly, alleviating the burden of persistent waste in the environment.

3. **Soil Remediation**: Nano biopolymers aid in soil remediation efforts by addressing soil pollution and enhancing soil quality:

   Organic Contaminant Removal: Nano biopolymer-based adsorbents can help remove organic pollutants and toxins from soil, improving its fertility.

   Soil Erosion Control: Nano biopolymer-based materials can stabilize soil structure, preventing erosion and promoting sustainable agricultural practices.

4. **Air Purification**: Nano biopolymer materials contribute to cleaner air through pollutant capture and removal:

   Air Filters: Nano biopolymer filters can capture airborne particles, allergens, and pollutants, improving indoor air quality in homes and commercial spaces.

   Volatile Organic Compounds (VOCs): Nano biopolymers can adsorb VOCs, reducing indoor air pollution and improving respiratory health.

5. **Renewable Energy**: Nano biopolymers support the development of sustainable energy solutions:

   Solar Cells: Nano biopolymer-based materials can be incorporated into solar cells to enhance energy conversion efficiency.

   Biomass Conversion: Nano biopolymers aid in the efficient conversion of biomass into biofuels, contributing to renewable energy sources.

6. **Bioremediation**: Nano biopolymers enhance bioremediation processes by facilitating the removal of contaminants through biological means. Nano biopolymer-based nanoparticles can deliver enzymes or microorganisms to polluted sites, accelerating pollutant degradation.

7. **Green Nanotechnology**: Nano biopolymers exemplify the principles of green nanotechnology by prioritizing sustainability and minimizing environmental impact. The use of biopolymers derived from renewable sources reduces the reliance on fossil fuels. Nano biopolymers typically exhibit lower toxicity compared to synthetic nanomaterials, reducing potential harm to ecosystems.

Agriculture Applications

- Crop Enhancement: Nano biopolymers can be used as carriers for controlled-release fertilizers, improving nutrient uptake and enhancing crop growth.

- Pest Management: Nano biopolymer-based formulations can encapsulate pesticides, enablingtargeted and controlled pesticide delivery, reducing environmental impact.

- Soil Health: Nano biopolymers can improve soil structure, water retention, and nutrientavailability, promoting sustainable agriculture practices.

Food Industry Applications

Food Additives: Nano biopolymers can serve as natural thickeners, stabilizers, and emulsifiers, improving food texture, taste, and shelf life.

Encapsulation: Nano biopolymer encapsulation protects sensitive food components, such as flavors, vitamins, and nutrients, ensuring their stability and controlled release.

Food Safety: Nano biopolymer-based sensors can detect contaminants or spoilage in food products, enhancing food safety and quality control.

Other Applications

- Cosmetics: Skin Care: Nano biopolymers can enhance moisturization, improve skin barrier function, and deliver active ingredients for more effective skin care products.
- Hair Care: Nano biopolymer-based products can strengthen hair, enhance texture, and provide long-lasting effects in shampoos, conditioners, and styling products.
- Sun Protection: Nano biopolymers can be incorporated into sunscreens, offering improved UV protection and skin comfort.
- Electronics: Flexible Electronics: Nano biopolymers can be integrated into flexible electronic devices, such as flexible displays and wearable sensors, due to their compatibility withorganic electronics.
- Dielectric Materials: Nano biopolymers can be engineered as dielectric materials in capacitors and insulating layers, enhancing energy storage and transmission efficiency.
- Biodegradable Electronics: Nano biopolymers enable the development of biodegradable electronic components, reducing electronic waste and environmental impact.

Challenges and Future Directions:

1. **Regulatory Considerations**: Regulatory agencies require thorough assessments of the safety and environmental impact of Nano biopolymers before widespread use. Developing standardized testing protocols for their evaluation is essential. Clear guidelines are needed to ensure the safe use of Nano biopolymers in various applications, particularly in the medical and food industries, to avoid unintended health or environmental consequences.

2. **Scalability of Production**: Scaling up the production of Nano biopolymers while maintaining consistent quality and properties poses challenges. Efficient and cost-effective large-scale manufacturing methods need to be developed. Ensuring the sustainable sourcing of raw materials, especially for marine and plant-based Nano biopolymers, is crucial to prevent overharvesting or negative impacts on ecosystems.

3. **Biodegradation Control**: While biodegradability is a desirable property, controlling the rate of biodegradation to match specific applications can be challenging. Balancing rapid degradation with durability is essential.

4. **Stability and Shelf Life**: Nano biopolymers can be sensitive to environmental factors, affecting their stability and shelf life. Developing strategies to enhance their stability over time is crucial, especially in applications with long product lifecycles.

5. **Functionality Retention**: Ensuring that Nano biopolymers maintain their desired functionalities throughout processing, storage, and application is critical for achieving consistent performance.

Ongoing Research and Future Advancements:

1. **Advanced Drug Delivery Systems**: Ongoing research aims to develop Nano biopolymer-baseddrug delivery systems with even greater precision, enabling targeted therapy at the cellular or even subcellular level.

2. **Multifunctional Nano biopolymers**: Researchers are working on Nano biopolymers with multiple functionalities, combining drug delivery, imaging, and sensing capabilities within a single material.

3. **Personalized Medicine**: The field of Nano biopolymers is moving towards personalized medicine, where treatments are tailored to individual patients based on their genetic and physiological profiles.

4. **Sustainable Packaging**: The development of Nano biopolymer-based packaging materials with improved barrier properties, biodegradability, and antimicrobial effects is gaining momentum to address plastic waste concerns.

5. **Green Electronics**: Nano biopolymers are being explored for use in biodegradable electronics, contributing to reduced electronic waste and environmentally friendly technologies.

6. **Controlled Release Systems**: Research is focused on enhancing the precision and controllability of Nano biopolymer-based controlled release systems for pharmaceuticals, nutrients, and agrochemicals.

7. **Nano biopolymers in Energy**: Nano biopolymers are being investigated for energy storage applications, such as supercapacitors and battery materials, due to their unique properties and environmental advantages.

Conclusion

Nano biopolymers represent a remarkable convergence of nanotechnology and biopolymers, offering a wealth of opportunities across diverse industries. Their significance lies in their ability to combine the inherent properties of biopolymers with the size-dependent effects of nanoscale materials, resulting in a range of materials with enhanced biocompatibility, biodegradability, and specific functionalities. Nano biopolymers have already revolutionized fields such as medicine, environmental remediation, agriculture, cosmetics, and electronics. They hold the potential to address critical challenges, from targeted drug delivery and tissue engineering to sustainable packaging and clean water solutions. These materials not only offer tailored solutions to pressing problems but also align with the growing emphasis on sustainability and eco-friendly technologies. As we look ahead, the exploration and research in the field of Nano biopolymers hold great promise.

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APPLICATION OF NANOMATERIALS FOR CORROSION RESEARCH

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Introduction

Corrosion is a familiar process wherein metals, notably steel, undergo deterioration, leading to the formation of undesirable substances and potential loss of function in components or systems. The most common visible outcome of corrosion is the formation of rust on steel surfaces,altering them from their original state.

Two fundamental reactions drive this process. Initially, the primary component of steel, iron (Fe), undergoes a series of basic changes: **$Fe \rightarrow Fe^{n+}$ + n electrons**

This transformation involves the loss of electrons by iron atoms, causing them to become positively charged ions. This change enables them to combine with groups of atoms that possess negative charges.

Considering that wet steel undergoes rusting, the complementary reaction involves the presence of water (H2O) and oxygen (O2). A possible representation of this reaction is as follows: **$O_2 + 2H_2O + 4e- \rightarrow 4OH$**

In this reaction, oxygen combines with water and accepts four electrons to create hydroxide ions. In a nutshell, corrosion involves the gradual transformation of iron atoms on the metal surface into charged ions, which then react with oxygen and water to create the rusting effect that we commonly observe.

Oxygen easily dissolves in water, and due to its abundance, it readily reacts with the iron hydroxide.

$4Fe(OH)_2 + O_2 \rightarrow 2H_2O + 2Fe_2O_3.H_2O$

Iron hydroxide → Hydrated iron oxide(Brown rust)

Brown rust

Corrosion involves ions, which rely on a medium like water. Oxygen is vital for rust formation. Metals must release electrons to kickstart the process. The corrosion sequence consists of simple steps propelled by an essential force impacting the rate of corrosion. Understanding and manipulating these factors enables control over corrosion.

Types of Corrosion

Corrosion occurring on a metal surface closely resembles the workings of an electrochemical cell. The metal experiences corrosion at the anode, while the surrounding corrosive medium acts as the electrolyte. Importantly, the cathode does not undergo consumption throughout this process. The pace of corrosion is dictated by the quantity of electron current that flows between the cathode and anode. Variations in the distribution of cathodic and anodic areas within the metal lead to distinct forms of corrosion.

1. Uniform Corrosion

Uniform corrosion refers to a reaction that evenly occurs across a material's surface, resulting in a gradual reduction in component thickness and eventual material failure. Metals lacking passive films, like steel and various others, are susceptible to this type of uniform corrosion. About 30 % of failure of material is by uniform corrosion.

Methods to combat uniform corrosion are, opting for alloys that boast enhanced corrosion resistance, achieved either through higher alloy content or the use of more inert alloys. Application of coatings that serve as barriers between the material and the surrounding environment, impeding the corrosive processes. By the addition of chemical inhibitors to alterthe corrosive environment itself. Implementing cathodic protection presents an additional method wherein an external electrical current is applied to safeguard the material against uniformcorrosion.

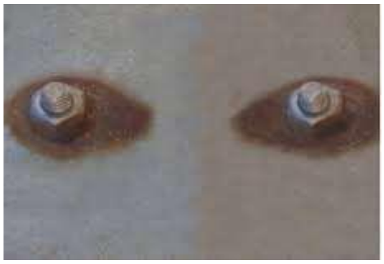
2. Localised corrosion

It can pose significant consequences than uniform corrosion that is about 70% of the material failure is by localised corrosion. Failure occurs without warning and even after short period of use.

2.1. Galvanic corrosion

When two metals are in electric contact and one is better at releasing electrons than other, galvanic corrosion occurs, provided there is an additional pathway for electron movement exist.

Techniques to resist galvanic corrosion are to break electrical contact via plastic insulators or coatings between the metals. Opt for metals positioned closely together in the galvanic series. Halt ion movement by coating the junction with impermeable materials or by maintaining a dry environment that prevents liquid entrapment. Area of anode should be larger than cathode (inert metal).




Examples of galvanic corrosion.

2.2 Pitting Corrosion

It is highly localised corrosion, occurs where there is a coating failure or a protective film like rust over the metal surface. Thus, exposed part of metal easily give electron forming pits and corrode easily.


Pitts formed as a result of corrosion

Pitting corrosion can be prevented by using inhibitors to control electrolyte chemistry, applying protective coatings, ensuring high fluid flow velocity, and maintaining the metal's natural protective layer.

2.3 Selective Attack

This type of corrosion is observed in alloys like brass, where one phase corrodes selectively, resulting in a porous, crumbling material. While choosing a resistant material is the primary prevention method, effective alternatives include coating, reducing environmental aggressiveness, and implementing cathodic protection.

Corroded surface as a result of Selective Attack

2.4 Stray Current Corrosion

This corrosion arises when unintended pathways conduct direct current, fueling electron-supported corrosion. Common in soils and in flowing and stationary fluids, prevention involve current control by:

- Insulating the structure or current source.
- Grounding sources and/or the structure.
- Employing cathodic protection.
- Implementing sacrificial targets.

2.5 Microbial Corrosion

Here material deterioration is caused by bacteria, molds, fungi, or their by-products. Various actions to prevent this degradation are:

- Acidic by-products, sulfur, hydrogen sulfide, or ammonia attacking metal or protective coatings.
- Microbes directly interacting with metal, perpetuating the degradation process.

Eg; submerged pipelines in soil, deposition in a water pipe line can generate accumulation of bacteria

Examples of Microbial Corrosion

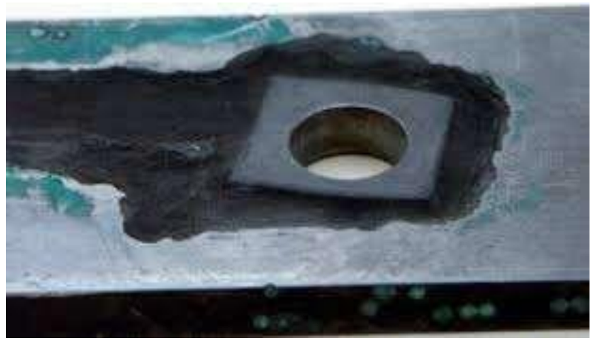
2.6. Intergranular Corrosion

This refers to selective corrosion at grain boundaries in metal crystals due to disparities between grain centers and edges. Preventive measures include:

- Opting for stabilized materials.
- Managing heat treatments and processing to avoid vulnerable temperature ranges.

2.7 **Concentration Cell Corrosion** (Crevice)

This is a type of localised corrosion which may occur in small areas of stagnant solution in crevices, joints, and under corrosion deposits. An example for crevice corrosion is that when oxygen cannot penetrate, an aeration cell is setup which trigger corrosion. Preventing the formation of stagnant zones and sharp corners is achieved by thoughtful design. Implementing sealants and favoring welds over bolts or rivets are effective measures. Additionally, the choice of materials resistant to corrosion contributes to comprehensive prevention strategies.



Examples of crevice corrosion

2.8. Thermogalvanic corrosion

Fluctuations in temperature impact corrosion rates; a 10°C increase doubles it. Temperature variations within a component intensify corrosion differences, causing local attack between hot and cold zones. Prevention involves erasing thermal gradients in design or introducing coolants for balance.

2.9. Stress Corrosion Cracking

It involves a static tensile stress and corrosion acting together, resulting in cracks and eventual component failure. This is exclusive to a metal matched with a specific environment. Prevention includes:

• Lowering stress levels and eliminating stress concentrations in design.

• Opting for a material resistant to the environment.

• Minimizing thermal and residual stresses in design.

• Inducing compressive surface stresses.

• Applying a suitable protective coating.

Cracking due to stress corrosion

2.10. Erosion Corrosion

Erosion corrosion arises from the interaction between a fluid and particulate matter within it. This effect is often exacerbated in scenarios where liquids flow through tubes, particularly at bends. The turbulent flow and impact of particles can cause mechanical harm to the internal tube surface,leading to erosion corrosion. In essence, the combination of fluid motion and solid particles accelerate the corrosive deterioration of the material, resulting in the progressivewearing away of the affected surface.

Corrosion of structures in contact with fluid

Among the different types of corrosion, marine corrosion (corrosion in marine or saltwater environments) has a special interest as the presence of salt and other minerals in the water accelerates the corrosion process. It often involves unique types of corrosion, such as galvanic corrosion, crevice corrosion, and pitting corrosion. Marine corrosion can impact structures like ships, offshore platforms, and coastal infrastructure, leading to rapid deterioration and requiring specialized corrosion prevention measures.

The fight against corrosion involves a range of professionals, from engineers to scientists, who incorporate anti-corrosion measures into their projects to counter the negative impacts of corrosion. And one such countermeasure is the use of nanomaterials.

Nanomaterials have found significant applications in the field of corrosion inhibitors. These materials, due to their unique properties at the nanoscale, offer enhanced protection against corrosion in various industries. Nanostructured coatings and films based on materials like nanoparticles, nanocomposites, and nanotubes have shown remarkable potential to create effective barriers against corrosives. The large surface area and high reactivity of nanomaterials enable them to form protective layers that hinder the penetration of corrosive species, thereby reducing the degradation of metal surfaces. These innovative corrosion inhibitors hold promise for extending the lifespan of materials exposed to aggressive environments and contributing to more sustainable and durable solutions in industries ranging from infrastructure to electronicsand beyond. As part of our CIFT initiatives, researchers have devised several antifouling strategies in conjunction with the implementation of nanotechnology.

In 2007, CIFT developed a novel technique for preventing corrosion in marine environments by reinforcing aluminium with cerium oxide (CeO_2).

Corrosion of aluminium in aggressive marine environments poses a substantial problem, impacting structural integrity. Traditional methods of using cerium ions for surface modification have demonstrated limited effectiveness. Researchers tackled this issue by employingaluminium-based metal matrix composites, leveraging the benefits of aluminium's density, strength, ductility, and cost. Through the incorporation of cerium oxide nanoparticles into the aluminium matrix, impressive outcomes were achieved, effectively suppressing corrosion in saline conditions.
Key achievements and highlights of the study include:

Effective Corrosion Suppression: Introducing cerium oxide nanoparticles into the aluminium matrix resulted in a notable decrease in corrosion rates under harsh marine conditions. This finding highlights the promise of cerium oxide as an effective corrosion-resistant material.

Aluminium Oxide Formation Control: In contrast to traditional methods that can lead to the creation of aluminium oxide (Al_2O_3), which contribute to pitting corrosion, the inclusion of cerium oxide nanoparticles within the matrix prevented the early development of aluminium oxide. This is a critical achievement, as pitting corrosion can be particularly destructive in marine environments.

Long-Term Stability: The research findings indicate that the protective benefits provided by the cerium oxide-enhanced aluminium matrix remain consistent over time, showing no signs of shifting or degradation caused by pitting corrosion. This long-term stability underscores the efficacy of the proposed method.

Nanotechnology Application: The research demonstrates the effective application of nanotechnology through the incorporation of cerium oxide nanoparticles into the aluminium matrix. Nanoparticles bring about improved material characteristics and surface interactions, thereby playing a pivotal role in the overall efficacy of the corrosion prevention approach.

In conclusion, the innovative research from CIFT introduces a novel strategy for tackling marine corrosion. By harnessing the strengths of aluminium and cerium oxide nanoparticles, the study showcases a hopeful remedy for enhancing the durability and functionality of aluminium structures in challenging marine settings. This accomplishment not only underscores the significance of cerium oxide but also highlights the effectiveness of nanotechnology in addressing practical issues.

A study conducted in 2020 represents a remarkable advancement in the application of nanotechnology to inhibit corrosion in boat-building carbon steel (BIS 2062). The research involves the synthesis of carbon nanodots (CDs) from chitosan. This study underscores the noteworthy progress achieved by utilizing nanotechnology and CDs as novel corrosion inhibitors.

Carbon Nanodot Synthesis from Chitosan: The research successfully synthesized fluorescent carbon nanodots (CDs) using chitosan, introducing an innovative method to generatenanoparticles with distinct characteristics. These CDs possess advantageous features like eco- friendliness, strong conductivity, low toxicity, and remarkable stability, making them a promising choice for diverse uses, including corrosion inhibition.

Corrosion Inhibition Performance: The carbon nanodots (CDs) was applied as a protective coating on BIS 2062 carbon steel, commonly used in boat construction. The electrochemical properties of the coated steel were assessed through methods like linear sweep voltammetry (LSV) and electrochemical impedance spectroscopy (EIS). Notably, the results showcased that the steel coated with a 0.05% CD solution displayed impressive corrosion resistance, highlighting the promising role of CDs as proficient corrosion inhibitors.

Suppression of Iron Oxide Oxidation and Reduction: The cyclic voltammetric evaluation using a glassy carbon electrode revealed that the oxidation and reduction potential of iron oxide were significantly suppressed due to the presence of CD coating. This observation highlights the CDs' capability to interfere with the corrosion process and protect the metal surface.

Potential Alternative to Graphene-based Materials: The research positions carbon nanodots (CDs) as a favorable substitute for graphene-based materials in corrosion inhibition. This advancement provides a more ecologically sound and effective approach to counteracting corrosion, emphasizing the unique properties of CDs to potentially enhance their efficacy.

In conclusion, the research highlights the effective application of nanotechnology by producing carbon nanodots from chitosan and using them as corrosion inhibitors for boat-building carbon steel. The incorporation of CDs demonstrates their ability to proficiently inhibit corrosion,improve material safeguarding, and present an alternative to traditional corrosion prevention approaches. This achievement emphasizes the potential of nanotechnology to tackle practical issues and propel materials protection in diverse industries forward.

In 2022, the research conducted by CIFT presents a pioneering breakthrough in utilizing nanotechnology for a green extraction process of nanocarbon dots (CDs) from prawn shells. These CDs are then subsequently integrated into epoxy polymers to create corrosion-resistant coatings. The study underscores the remarkable achievements resulting from this novel approach.

Utilization of Waste Materials: The study focuses on the exoskeletons of prawn, shrimp, and crab, which are commonly discarded as waste. These exoskeletons contain valuable inorganic and organic constituents. The research emphasizes the significance of not only retrieving chitin but also other organic components from these discarded materials.

Nanocarbon Dot Synthesis: The researchers successfully synthesized nanocarbon dots through a hydrothermal carbonization process. This environmentally friendly technique utilizes waste materials to generate valuable nanomaterials with distinct properties.

Corrosion Resistance Enhancement: The epoxy polymer composite coated over the steel surface demonstrated enhanced resistance against corrosion. This result highlights the capability of nanocarbon dots as beneficial additives for enhancing the protective properties of polymer coatings.

Interaction with Polymer Matrix: The chemical and morphological analysis of the epoxy polymercomposite revealed the interaction between the nanocarbon dots and the polymer matrix. Notably, the presence of NH_2 functional groups in the nanocarbon dots synergistically acted with the hardener to create a pore-free epoxy coating.

Dual Product Extraction: The research not only produced nanocarbon dots but also extracted chitin from prawn shells through the hydrothermal process. This dual-product extraction demonstrates the economic and environmental advantages of the suggested green synthesis procedure.

In conclusion, the research conducted by CIFT showcases the effective application of nanotechnology in environmentally-friendly processes to extract nanocarbon dots and chitin from prawn shells. The incorporation of nanocarbon dots into epoxy polymers for corrosion- resistant coatings emphasizes their capacity to enhance material properties and overall performance. This accomplishment highlights the substantial impact of nanotechnology-driven innovations in converting waste materials into valuable products, with a wide range of applications, ultimately contributing to economic and environmental sustainability.

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FISHING GEAR MATERIALS: PROPERTIES &DEGRADATION PATTERN

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Introduction

Netting materials for fabrication of fishing gear are either of textile or non-textile origin. The raw material for fish netting consists of fibres that can be distinguished into two groups: natural fibres and man-made fibres. Different kinds of fibres originating from plant and animal body parts have been used for production of textiles and other products are termed as natural fibres. Traditional fishing gears used earlier, till 1950s were mainly with natural fibres such as cotton, manila, sisal, jute and coir. Natural polymers and synthetic polymers constitute man-made fibres. Natural polymers are manufactured by the alteration of natural polymers like cellulose and proteinwhile synthetic polymers are obtained by synthesis or chemical process. Man-made fibres derived from cellulose eg: rayon, are susceptible to microbial deterioration while synthetic fibres are very resistant to bio deterioration. In the late 1950s, with the introduction of man-made synthetic fibres, natural fibres used for the fishing gears have been substituted by these synthetic materials. This transition was mainly due to the highly positive properties of these fibres such as highly non- biodegradable nature, high breaking strength, better uniformity in characteristics, high abrasion resistance, low maintenance cost and long service life.

Synthetic Fibres

Synthetic fibres are produced entirely by chemical process or synthesis from simple basic substances such as phenol, benzene, acetylene etc. The chemical process involves the production of macromolecular compounds by polycondensation or polymerization of simple molecules of a monomer. The raw materials are petroleum, coal, coke and hydrocarbon. Depending on the type of polymer, synthetic fibres are classified into different groups and are known by different names in different countries. Altogether seven groups of polymers are developed; most important polymer/synthetic fibres used in fishing gears are polyamide (PA), polyester (PES), polyethylene (PE) and polypropylene (PP). Other synthetic fibres, which are less widely used and generally restricted to Japanese fisheries, are polyvinyl alcohol (PVA), polyvinyl chloride (PVC) and polyvinylidene chloride (PVD). Aramid fibres, Ultra high molecular weight polyethylene (UHMWPE) and liquid crystal polymer are later additions to this group.

Polyamide (PA**):** Polyamide, a synthetic polymer, popularly known as nylon, invented in 1935 refers to a family of polymers called linear polyamides. Nylon consists of repeating units of amide with peptide linkages between them. Depending on the raw material and method of making two types of nylon viz., PA 6 and PA 66 are available for fibre applications. PA 66, widely used for fibres is made from adipic acid and hexamethylene diamine while PA 6 is built with caprolactam. With regard to the fisheries, there is no difference between PA 66 and PA 6, while in India, for fishing purposes PA 6 is used. The softness, lightness, elastic recovery, stretchability and high abrasion and temperature resistance are superior properties inherent to nylon. However, high moisture absorption along with dimensional instability and requirement of UV stabilization are its disadvantages. On wetting, nylon loses up to 30% of tensile strength and 50% of tensile modulus.

Polyolefins*:* Polypropylene (PP) and Polyethylene (PE) are often collectively called "polyolefins". Polyolefin fibres are long-chain polymers composed (at least 85% by weight) of ethylene, propylene or other olefin units. Polyolefin fibres are made by melt spinning. They do not absorb moisture and have a high resistance to UV degradation.

Polyethylene (PE): PE fibre is defined as: "fibres composed of linear macromolecules made up of saturated aliphatic hydrocarbons". PE fibres, used for fishing gear, are produced by a method developed by Ziegler, in the early 1950s.The monomer ethylene, the basic substance of polyethylene, is normally obtained by cracking petroleum. Linear polyethylene or high-density polyethylene has high crystallinity, melting temperature, hardness and tensile strength. In India, PE is used for manufacture of netting and ropes.

Polypropylene (PP): PP fibre is defined as: "fibres composed of linear macromolecules made up of saturated aliphatic carbon units in which one carbon atom in two carries a methyl side group". This is an additive polymer of propylene. PP was commercialized in 1956 by polymerizing propylene using catalysis. Though PP netting and ropes are available, in India, PP is mainly used for ropes.

Polyester (PES): The principal PES fibres are made from polymerization of terepthalic acid and ethylene alcohol. It was first synthesized by Whinfield and Dickson of Great Britain in 1940-41 and named the fibre "Terylene".

Recent Advances in Synthetic Fibres

Introduction of synthetic materials with high tensile strength properties has made it possible to bring out changes in the design and size of fishing nets. As the fishing industry became highly competitive, the search and research for new generation materials which give better strength for less thickness resulted in invention of new materials. Aramid fibres, Kevlar, UHMWPE, biodegradable plastic etc are recent introductions to the fishing gear material sector. These materials have advantages, especially less drag which results in fuel efficiency. The performance of UHMWPE webbing and rope in the Indian context is being studied by ICAR-CIFT. Among the new fibre types, only Sapphire and UHMWPE are used on a commercial basis for fishinggear viz., trawls and purse seines in Australia and Alaskan waters. Sapphire is also used on a limited scale in large mesh gillnets targeting large pelagics in Maharashtra region of India.

Ultra High Molecular Weight Polyethylene (UHMWPE): UHMWPE is a type of polyolefin synthesized from monomer of ethylene processed by different methods such as compression molding, ram extrusion, gel spinning, and sintering. Polyethylene with an ultra-high molecular weight (UHMWPE) is used as the starting material. In normal polyethylene, the molecules are not orientated and are easily torn apart. The fibres made by gel spinning have a high degree of molecular orientation with very high tensile strength. The fibre is made up of extremely long chains of polyethylene, which attains a parallel orientation > 95% and a level of crystallinity of up to 85%. The extremely long chains have molecular weight usually between 3.1 and 5.67 million while HDPE molecule has only 700 to 1,800 monomer units per molecule.

UHMWPE, also known as high modulus polyethylene (HMPE) or high performance polyethylene (HPPE) is a thermoplastic. It has extremely low moisture absorption, very low coefficient of friction, is self-lubricating and is highly resistant to abrasion (10 times more resistant to abrasion than carbon steel). This is available as Dyneema and Spectra produced by two different companies. Commercial grades of Dyneema fibres SK 60 and SK 75 are specially designed for ropes, cordage, fisheries and textile applications.

UHMWPE is 15 times stronger than steel and up to 40% stronger than Kevlar. UHMWPE netting is 3 times stronger than nylon with the same dimension, and increases the net's strength while the abrasion resistance increases the net's life. Netting can be used for trawl nets, purse seine nets and aquaculture nets. Nylon purse seines last for about 2-3 years while UHMWPE netting ensures 2-3 times more life for the net. The netting twines made with Dyneema fibre can be reduced by upto a factor of 2 on thickness (diameter basis) and on weight basis by a factor of

4. This allows fishing vessels to increase their catch potentially by as much as 80% by trawling faster or using larger nets, or to reduce fuel consumption. Besides, less deck space is required due to lower bulk volume of the net. Purse seines made of Dyneema would facilitate 40% increase in sinking speed due to better filtering and reduced drag. Larger net for the same weight can be made. The net has better durability with negligible wear & tear.

Sapphire: Sapphire PE netting manufactured from specialized polymers available in twisted and braided form is suitable for trawl nets and for cage culture. It has the highest knot breaking strength, knot stability and dimensional uniformity. Braided twine having compact construction restricts mud penetration and provides lesser drag. Sapphire is used on a limited scale for fabrication of large mesh gillnets targeting large pelagics in Maharashtra region of India. Sapphire ultracore is a knotless HDPE star netting with an outer layer of heavier sapphire ultracore which features strands of marine grade stainless steel as an integral part of the netting twine. The stiffness and cut resistance enable it to be used as a predator protection net cum cage bag net where the predation problem is very high.

Aramid Fibres: Aramid fibres are fibres in which the base material is a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings. Two types of aramid fibres are produced by the DuPont Company: Kevlar (para-aramid) and Nomex (meta-aramid), which differ primarily in the substitution positions on the aromatic ring. Generally, aramid fibres have medium to very high tensile strength, medium to low elongation-to-break, and moderate to very high modulus.

KEVLAR® polyphenylene terephthalamide (PPTA): A polymer containing aromatic and amide molecular groups is one of the most important man-made organic fibre ever developed. Because of its unique combination of properties, KEVLAR® is used in the fishing sector as netting, fishing rod and fishing line. Fibres of KEVLAR® consist of long molecular chains produced from poly (p-phenylene terephthalamide). The chains are highly oriented with strong interchain bonding, which result in a unique combination of properties. The strength to weight ratio of Kevlar is high; on a weight basis, it is five times as strong as steel and ten times as strong as aluminum. It has high tensile strength at low weight, low elongation to break, high toughness (work-to-break), and excellent dimensional stability. In sea water, ropes with KEVLAR® are upto 95% lighter than steel ropes of comparable strength.

Liquid Crystal Polymer Fibre: Vectran®, a high-performance thermoplastic multifilamentyarn spun from Vectra® liquid crystal polymer (LCP), is the only commercially available melt- spun LCP Fibre in the world. Vectran fibre is five times stronger than steel and 10 times strongerthan aluminum. Vectran fibre is 4 times stronger than polyethylene fibre or nylon fibre. The unique properties that characterize Vectran fibre include: high strength and modulus; high abrasion resistance; minimal moisture absorption; and high impact resistance. Although Vectran is lacking UV resistance, this limitation can be overcome by using polyester as a protective covering. It is very suitable for trawl nets and ropes.

Fluorocarbon Fibre: Fluorocarbon fibre is a new material that can be used in angling and high-speed jigging lines. It has very high knot strength, almost invisible in water, has high breaking strength and abrasion resistance.

Properties

As far as the fishing gear purpose is concerned, properties which are of importance are linear density, diameter, specific gravity, knot stability, breaking load, elongation, weathering resistance and abrasion resistance.

Diameter: The diameter of netting material is an important factor influencing the fishing gear performance. Thickness and rigidity of the material influences the resistance of fishing gear to water flow and hence the power required or the speed obtained in towing gears are depended on it. Thinner twines offer less resistance. Diameter of a material is dependent on the type of polymer, type of yarn, size of yarn, specification and construction. Diameter is expressed in mm and is measured using a travelling microscope or a micrometer.

Linear Density: It is the mass per unit length of the material. The mass in g of 1000 m length of amaterial is expressed as R tex and mass of 9000 m of the material as R denier. While comparing different types of yarns, the Rtex values serve as a relative measure for the mass of netting. For the same kind of material, lower Rtex means thinner material and generally costs less while buying on a mass basis.

Specific Gravity: Specific gravity of most of the synthetic fibres is less than the natural fibres.

Specific gravity influences the fishing gear as fibres with lesser specific gravity allows a greater length of netting for a given weight of yarn and helps in savings in handling and power. However, for a gear such as purse seine, material with very low specific gravity is not the suitable one as quick sinking of the net is a prime requisite to capture a shoal of fish.

Twist: The number of turns or twists imparted to a twine per unit length is important as it influences many properties especially the breaking strength, diameter, linear density, resistance to abrasion and general wear and tear of the twine. As the amount of twist increases the breaking strength also increases up to a critical degree of twist beyond which it would weaken the twine. The stability of a twine depends on the correct amount of twists per unit length. The twine has an inner/strand/primary twist and outer/secondary/twine twist. Balance between these two twists ie: primary twist for making strands from yarns and secondary twist to make twine from strands is important. Twines with a well-balanced twist do not have a tendency to snarl.

Breaking Strength and Elongation: The breaking strength/load of a material denotes the ability of a material to withstand the strain. It depends on the type of polymer, type of yarn, degree of twist and thickness of the material. Tenacity is the breaking load in terms of yarn denier while tensile strength is the force in terms of unit area of cross section. The strength of fibre changes in the wet condition; in natural fibres the wet strength is higher while the reverse is true of synthetic fibres. Knotting also causes reduction in the breaking strength. This is dependent on the type of polymer, type of yarn and knot, twine construction and also on the degree of stretching. Breaking load is expressed in Newton (N).

Elongation is the increase in the length of a specimen during a tensile test and is expressed mostly in percentage of the nominal gauge length. Extensibility is the ability of a netting material to change its dimension under a tensile force. It involves a reversible and an irreversible elongation. Irreversible or permanent elongation is the part of the total increase in length which remains after the removal of the stress. Reversible or elastic elongation is the part of the total increase in length which is cancelled again, either immediately or after a long period of removal of stress.

Weathering Resistance: Even though all fibres, irrespective of natural or synthetic are prone to degradation on exposure to weathering, the problem is severe with synthetic fibres. The effect of weathering depends on the thickness of yarn, as thicker twines show better resistance. This is because the layers below are protected by the degraded outer layers and generally UV rays do not penetrate more than 1mm. By dyeing the weathering resistance can be improved. PVC has very high resistance against weathering, while PES has high and PA and PE, have medium resistance against weathering. Among different types of fibres, monofilament form is more resistant than multifilament and staple yarn.

Abrasion Resistance: The resistance of netting materials to abrasion, ie, abrasion with hard substances such as boat hull, sea bottom and net haulers, or abrasion between yarns/twines is important in determining the life of a net. The resistance to abrasion depends on the type of fibre, thickness and construction of the material. Polyamide has the maximum abrasion resistance, followed by PP, PES and PVC. The better abrasion resistance of PA is due to the inherent toughness, natural pliability, and its ability to undergo a high degree of flexing without breakdown. Among different types of materials, monofilament is better than multifilament, and between staple and multifilament, the latter is better. Abrasion can cause rupture of the material as also reduction of mesh size due to the internal abrasion caused by the friction of the fibres against each other.

Degradation of Fishing Gear Materials

Synthetic netting materials are generally resistant to biodeterioration i.e., they are resistantagainst destruction by mildew in air and bacteria in water. Weathering causes modification and breakdown of the molecular structure of polymers, which in turn results in the loss of strength, extensibility, general durability and appearance. Sunlight was considered to be the most important factor in weathering and the strongest deterioration effect was caused by ultra-violet part of sun's radiation followed by temperature and oxygen. Different synthetic fibres show variation in their susceptibility and rate of deterioration by sunlight depending on the type of polymer and fibre.

Degradation of Mechanical Strength Properties

The most important property for selection of netting twines for making fishing nets are its breaking strength, elongation at break and good resistance to environmental influences (such as UV radiation and temperature). Among these, breaking strength is the most important for nets and ropes, and should be as high as possible (Wanchana *et al*., 2002). In most of the degradation studies in fishing nets due to weathering and light exposure, reduction in breaking strength was commonly used as measure of degradation. The deteriorating action due to solar radiation usually occurs while the fishing net is in operation and also when taken to and from the fishing ground. This reduction in strength may be augmented by the fisherman's practice of exposing nets to sunlight for drying after returning from fishing. Deterioration due to weathering is more rapid at certain locations than others because of difference in duration of that particular wavelength of light, which damages the fibre.

Due to weathering when reduction in strength of nets occurs, the chances of theirbreakage/damage are more which may ultimately lead to loosing net parts or the entire net into the aquatic ecosystem. Since these fishing nets are made of plastic materials, they may cause negative ecological impacts to the marine environment due to macro- and microplastic pollution resulting from plastic degradation and weathering (Gilman, 2015). These lost nets may continue to capture/entangle fishes and other aquatic organisms which may ultimately lead to their mortality referred to as ghost fishing. Thus, changes in strength characteristics of nets due to the effects of weathering have considerable technical as well as environmental significance also

The service life of fishing net material is assessed based on the 50% retention of strength or elongation. Studies on PA monofilament and multifilament had shown, on an average (irrespective of thickness of different samples) 44% of breaking strength loss occurs at the end of180 days whereas loss was higher for PA multifilament (64%) for the same period of exposure. Also the thicker the monofilament, the twine or the rope, the better is the resistance since there is proportionately less depth penetration by ultraviolet rays (Radhalakshmy and Nayar, 1973). This could be explained by the fact that photo-oxidation was primarily a surface reaction, so the effect of UV radiation may not extend into the polymer bulk to any large extent. Hence, protecting fishing nets from direct sunlight should increase their service life. As weathering affects the longevity and efficiency of materials, the study on effect of weathering on these materials is important. Weathering can be studied by exposing samples to natural weathering conditions orby artificial weather simulating conditions. Natural exposure studies take much longer time (1 yr to 20yrs). The accelerated UV tests permit a realistic extrapolation of mechanical properties which aid in predicting the serviceability.

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CONCEPTS OF BIOFOULING IN THE MARINE ENVIRONMENT

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Introduction

Fouling in the aquatic environment is considered as unwanted deposits or accumulations of materials on the exterior of water-contacting materials. The material that accumulates may be non-living, comprising detritus and organic or inorganic compounds, but it may also include organisms that may range in size from microscopic viruses up to giant kelps, which can go on to form complex multi-species, multi-dimensional communities. Fouling is categorized into three such as inorganic fouling, organic fouling and biofouling. As a result of physical and chemical effects like heat, pressure, and friction or by natural process minerals within the water stacked at the surface of the materials are immersed in the water and cause inorganic fouling. Biofouling as a process means biological fouling and is a general term used to describe both the microbiological and macro-biological growths that occur on the exposed exterior of materials. Marine biofouling has been a major problem for man since the ancient maritime explorations andinitial human engagement with the ocean through artificial structures. This issue was recognized 2000 years ago and mentioned even by early Phoenicians and Carthaginians.

Biofouling and Fouling Organisms

Biofouling is a multi-stage process and it develops sequentially from an initial condition layer of absorbed organic and inorganic matter in the aquatic environment. Biofouling is defined as the undesirable accumulation of living organisms on exposed artificial surfaces in the aquatic ecosystem by adhesion, growth and reproduction. When it occurs in the marine environment it is called marine biofouling. Marine biofouling accumulates on surfaces in five succeeding stages such as initial attachment, irreversible attachment, initial growth, final growth, and dispersion. Most aquatic fouling organisms prefer hard substratum for settlement. It was estimated that about 127,000 aquatic species depend on hard surfaces for living while 30,000 depends on soft surfaces (*Gizer et.al*, 2023). However, a wide range of micro and macro- organisms can contribute to marine biofouling and approximately 5,000 species of marine biofouling organisms occur in the world, of which 2,000 species are recorded (Tseng and Huang, 1987). Marine biofouling can be divided into two main categories based on the size of organisms that accumulate and attach to the water contacted surfaces such as microfouling and macrofouling. Microscopic organisms like bacteria, viruses, protozoa, diatoms, fungi, and microalgae form microfouling. Macrofouling organisms directly depend on microfoulers. Microfouling is essential for the settlement of more complex macrofouling organisms. Macrofouling organisms are further classified into two based on the body structure of the colonizing organisms namely soft and hard macrofouling organisms.

Macroalgae, soft corals, anemones, tunicates, and sponges-like organisms with no solid/calcareous supporting structure are considered soft macrofouling organisms and organisms with hard supporting structures are hard macrofouling organisms such as barnacles, tubeworms, bivalves, and polychaetes which are difficult to remove once established. Some organisms bore more deep to the submerged andfouled materials such organisms are called borers. Organisms bore either for shelter or for food.The boring behavior of organisms directly destroys the submerged woods, rock, and other materials.

Processes Behind Biofouling

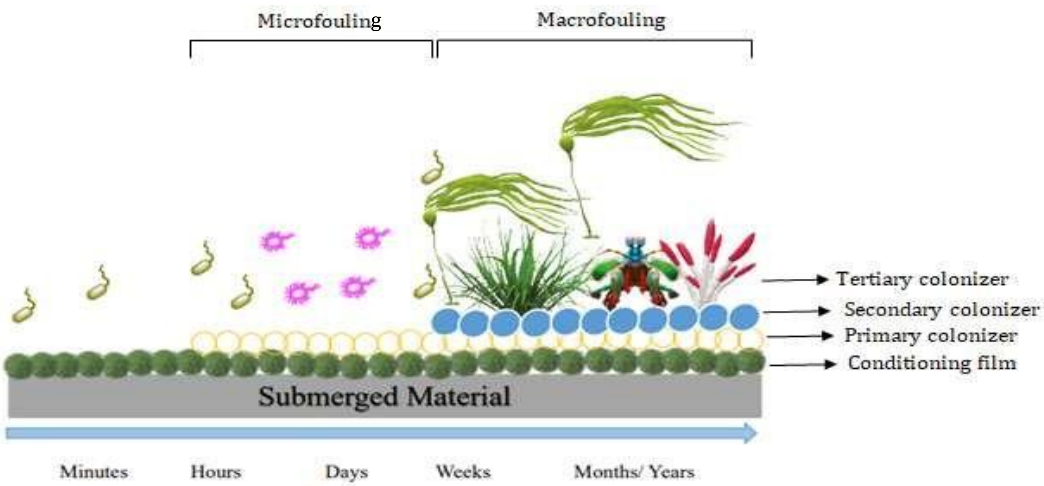
The processes of biofouling consist of five elementary processes such as transport, settlement, attachment, development, and growth. All these elementary processes replace each other sequentially during surface colonization by foulers. The colonization processes consist of two models such as probabilistic model and succession model or classic model. Prior tocolonization, film formation is the crucial step. Organic conditioning film formation is an important process in marine biofouling. Marine biofilm formation is a highly dynamic combination of chemical, physical, and biological processes that occurs within seconds of the initial interaction between exposed material and an aquatic ecosystem. Once a new surface, whether biotic or abiotic immersed in seawater can quickly adsorb organic matter that forms a nutrient-rich layer within a minute, in other words, it is described as the organic conditioning film. The formation of organic conditioning film is the result of a simple physical reaction, and itis comprised of colloidal organic matter and molecules such as polysaccharides, proteoglycanand proteins.

Organic conditioning film formation is the first step of marine biofouling and that result in the development of a stickier surface and which makes the exposed surface more favorable for the attachment of bacteria. The attachment of bacteria to the conditioning film results from the metabolism of organisms, as a result, they adhere to the surface faster and leadto the development of bacterial colonization. The sequence of colonization consists of bacteria, diatoms, autotrophic flagellates, heterotrophic flagellates, amoebae, heliozoans and ciliates. This sequential colonization process is known as succession or microfouling and the resulting layer is termed as microfilm/biofilm/marine biofilm. Diatoms are considered the major contributor to the primary colonizer. The reversible adsorption and irreversible adhesion are the two distinct steps involved in the microorganism colonization. The reversible adsorption is governed mainly by physical effects such as Brownian motion, electrostatic interaction, gravity, water flow and van der Waals forces. The irreversible adhesion occurs mainly through biochemical effects such as the secretion of extracellular polymeric substances. Within the biofilm, bacteria can coordinate their adhesion, biofilm maturation, swarming, luminescence and toxin production through a process known as quorum sensing.

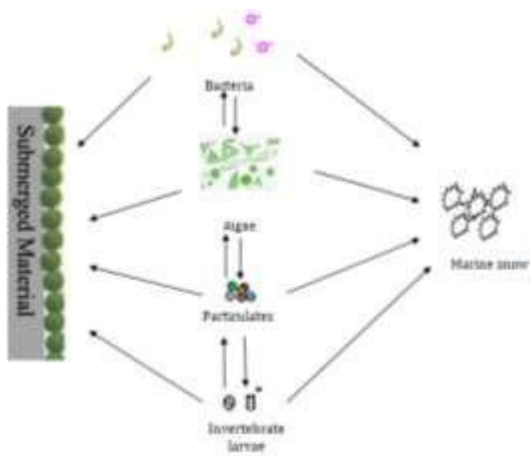
Quorum sensing is a process that involves producing, releasing, detecting, and responding to small hormone-like molecules termed autoinducers that are released into the environment by bacteria. Some bacteria and marine organisms like algaecan respond to the quorum sensing signals of other bacteria. The development of a biofilm on a substratum changes the attractiveness of the substratum to invertebrate larvae and algal spores through physical modification of surfaces or by production and release of chemical compounds. In the next stage of marine biofouling, propagules of microorganisms, larvae of invertebrates, and spores of macroalgae will settle on the surface. Two or three weeks later, these will finally evolve into a complex biological community. Microfouling is the first stage of succession of hard-substrate community and it is also considered the second step in marine biofouling.

The colonization process is broadly described as a biological succession. The rod-shaped chemoheterotrophic bacteria (e.g., *Pseudomonas*) are considered primary colonizers on the submerged surfaces. They appear on the conditioning film within 1 or 2h or earlier and may prepare the microconditions for the development of filamentous and stalked bacteria at the final stage of bacterial succession. Bacteria stimulate the fouling and development of diatoms. Succession may be based on the facilitation by early-species by creating conditions favorable for the late succession species. So the primary colonizers create conditions for secondary colonizers (spores of macroalgae, protozoa) this process continues until the development of tertiary colonizers. The first stage of macrofouling succession is by fast-growing and the second stage is by slow-growing organisms and succession ends with a short-term climax stage. This classic succession model oversimplifies the colonization process implying stage to stage.

The absence of a stage does not impede the occurrence of another stage and suchcolonization process follows a more dynamic and probabilistic model. In probabilistic model, some species like acorn barnacle and bryozoan's species may settle on the surfaces without the presence of a conditioning film and biofilm. The colonization process is dependent on the number and type of organisms and the attachment of organisms on substratum are independent ofone another. The absence of a surface may result in the aggregation of foulants and form marine snow and it remains in the seawater. That entrapped the propagules of microorganisms, larvae ofinvertebrates, and spores of macroalgae and it may gradually settle to a substratum that will allow the growth after attachment.



Succession model



Probabilistic model

Factors Influencing Marine Biofouling

The abundance and composition of marine biofouling communities vary greatly geographically, seasonally, locally across depths and different levels of wave exposure and alongwith the influence of abiotic and biotic factors. The abiotic factors include the hydrodynamic conditions, characteristics of substratum, and physical-chemical characteristics of seawater. The hydrodynamic conditions consist of current, velocity, wave exposure, distance to shore, and depth. The physical-chemical characteristic includes temperature, pressure, pH, dissolved oxygen, organic matter content, and pollution. The substratum features such as material composition, colour, roughness, period of submersion and motion also influence the settlement and growth of foulers.

Water Current, Velocity, Depth, And Distance of Submerged Materials from The Shore

The community structure of marine biofouling organisms is directly influenced by water current, velocity, and distance to shore. The impact of currents and water flow on biofouling communities depends on the velocities and shear forces. The impact of water velocities on the prevention of marine biofouling varies with species and condition of flow. Generally marine fouling organisms like mussels, barnacles and tubeworms are sessile and they get benefit from water currents in the form of feed. Macrofoulers like bivalves feed on suspended particles in the water or nutrients dissolved in the water so water currents provide enough nutrients for the development of macrofouling. Even though the water currents carry motile larvae of many invertebrates and the spores of algae to the offshore and the closure is the substratum to the shorehigher the probability of colonization success. While strong currents may dislodge organisms from the substratum to cope with this difficult environment the adult form of many sessile marine biofoulers such as barnacles have developed sophisticated mechanisms for strong surface adhesion. The lower flows may facilitate the settlement of larvae and spores of biofoulers.

Seawater Temperature, Pressure, Light Availability

Temperature is an important environmental parameter and it is closely related to latitude and seasonality. It is a major geographical determinant of the composition of marine biofouling. Seawater temperature influences the spawning period, settlement, growth and reproduction of organisms. The growth rate of biofouling organisms increases with temperature and that implies the low fouling rate in the polar areas and it occurs typically during mid-summer. Biofouling is more intense in tropical areas due to the warm temperature and which allows continuous reproduction and increased growth rate. In temperate areas, biofouling is closely related to the season. So, the spawning and growth of fouling organisms occur from spring to autumn in temperate regions. Depth, availability of light, and pressure greatly influence the community structure of marine biofoulers. The reduced microbial activity in the deep sea is attributed to the coeffects of temperature and pressure. The inhibitory effects of pressure on protein synthesis result in very slow microbial activity in ocean depths, microfilm formation and their compositionis less in deep. Photosynthetic organisms directly depend on the availability of light. The decrease in light availability decreases the composition of photosynthetic organisms in the marine biofouling community. The biofouling growth and biomass decrease with depth due to decreased light intensity. Despite the decrease in biofouling pressure with depth, the climax community such as mussels and barnacles constitute the bulk of macrofouling.

Substratum Features

The greater diversity and stable marine biofouling are associated with the biologically and chemically inert substrate. The physical-chemical properties of materials can affect the water chemistry and seawater–substratum interface chemistry which influences the formation and nutrient composition of the macromolecular conditioning layer. Materials like aluminium, carbon steel and bronze are more susceptible to marine biofouling than materials like glass fiber, polyethene, polyamide and rubber. The response of biofoulers is influenced by fouling species, depth, and heterogeneity of the substratum. Heterogeneity enables higher diversity and lower competition between species. The ability of organisms to adhere to a substratum is influenced by microtopography, roughness and texture. The color of substratum can be a determinant of biofouling settlement and it relates to the amount of energy reflected and absorbed by the substratum. The biofouling communities become more complex; differences between darker and lighter substrate should become negligible.

Impacts of Marine Biofouling

The adverse effect of marine fouling on vessel hulls still exists and it occurs on the vesselhull, propeller blades, fuel lines, etc. Macro-biofouling makes the vessel heavier and the hull rougher which leads to an increase in frictional resistance which results in a loss of the speed of the vessel which may decrease by 40% or more. The fuel consumption increases by about 40%.A layer of microbial slime of 1mm thickness can increase hull friction by 80% and cause a 15% loss in vessel speed. Frictional resistance increases with sufficient strong fouling of the hull by both micro and macro biofouling. While in some cases, the biofouling on the propeller blades isa more important cause of fuel waste. Biofouling indirectly influences the carbon footprint of vessels and greenhouse gases in the atmosphere, that is a 5 per cent increase in biofouling causes 17 per cent increase in fuel consumption by ships which leads to 14 per cent increase ingreenhouse gases (CO_2, NO_x, and SO_2) emission. On the other hand, heavy biofouling of fuel lines cause engine failure and a greater danger is observed by the fouling of heat exchangers. Biofouling accelerates the corrosion of metal walls. Docking frequency and other prevention methods such as antifouling coating are the widely used method for controlling biofouling. Up to200-400 tons of fouling biomass may be removed in one docking. Dry docking operation is moreexpensive and time-consuming moreover it generates a large number of toxic substances that are discharged into the ocean.

Biofouling Management

Protection of technical and biological objects from biofouling includes a range of existing and emerging approaches. The protection can be based on physical and chemical factorsor jointly. The process of biofouling occurs by both physical and chemical reactions. Theprotection can be easier by successful inhibition of the physical reactions which would constrain the later biochemical reactions. The different methods used for controlling biofouling include scrubbing off the fouling (docking), Autoclaving and plasma pulse technology, UV Radiations, use of remotely operated marine robotics for removal of biofilm and macrofouling from vessel hull, continuous bubble streams, high-frequency vibration, and biological control. The existing chemical, physical, and biological antifouling methods have not successfully tackled biofouling problems effectively and sustainably. Therefore, new surface technologies in combination with current methods should be developed by considering ecological effects.

Conclusion

The phenomenon of biofouling presents a complex and multi-stage process that significantly impacts aquatic environments and various industries. The accumulation of unwanted materials, organic compounds, and living organisms on submerged surfaces poses challenges to vessel efficiency, environmental impact, and infrastructure integrity. The intricate interplay of physical, chemical, and biological factors shapes the development and succession of marine biofouling communities.

Biofouling unfolds in a series of sequential stages, from initial attachment to dispersion, involving the colonization of surfaces by a wide range of organisms. Microfouling and macrofouling play integral roles in this process, each contributing to the formation of complex ecosystems that adhere to artificial structures.

The adverse effects of marine biofouling are manifold, impacting vessel performance, fuel efficiency, greenhouse gas emissions, and infrastructure integrity. The imperative to mitigatethe negative consequences of marine biofouling has prompted the development of a range of biofouling management strategies, from traditional dry docking to innovative technologies such as plasma pulse, UV radiation, and remotely operated marine robotics and nano particle based antifouling coating.

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NANO-TECHNOLOGICAL INTERVENTIONS FOR THE PREVENTION OF BIOFOULING IN AQUACULTURE CAGES

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Introduction

In an era marked by an ever-expanding global population, the quest for sustainable nutrition sources has intensified, triggering a heightened demand for food production. Amidstthis quest, aquaculture has emerged as a pivotal solution that offers both economic prosperity and enhanced food security. Various techniques for aquaculture such as RAS, bio-floc, and Cage culture, have gained substantial popularity and that driving the industry's growth. However, the persistent challenge of biofouling, particularly in cage aquaculture within marine and inland settings, poses a formidable hurdle to achieving efficient and sustainable production. The enduring development of the aquaculture industry is a key factor in the strategy to guarantee global nutritional safety. Nanotechnological interventions in cage aquaculture refer to the application of nanotechnology to improve various aspects of cage-based aquaculture systems. Nowadays, different types of nanotechnology-based systems have been employed to increase aquaculture production, efficiency and sustainability. In cage aquaculture one of the threats is disease spreading and its management. Nanoparticles can be designed to deliver targeted treatments such as vaccines or antimicrobial agents to combat diseases that affect culturedaquatic species (for example; DNA nano vaccines in nanocapsules). Cage aquaculture is generally practiced in lotic ecosystems so monitoring of environmental parameters is difficult butit is essential for successful farming. Nano sensors can monitor various parameters in real time such as water temperature, pH, and dissolved oxygen and ammonia levels. Nano sensors aid in the prompt detection of any unfavorable conditions. In addition, recent efforts have been made inthe fields of processing and preservation of seafood and water treatment, enhancement of fishand shellfish development by dietary supplementation with nutraceuticals, and Nano sensors to monitor stock. Therefore, nanotechnology has a significant role to play in the improvement ofthe efficiency and the environmental impact of aquaculture. Application of nanotechnology in aquaculture cages and cage nets is considered the effective way to controlling the biofouling in cages and can be efficient and sustainable aquaculture production through cage can ensure.

Cage Aquaculture

Cage aquaculture is considered as a method of rearing or raising fish or any aquatic organisms in an enclosed space or caged enclosure while in captivity that maintains the free flowof water with the surrounding water body. Cage aquaculture is a low-impact farming practice with high profit in terms of harvest and price. Nowadays cage aquaculture is receiving more attention from commercial producers and farmers. Mainly due to the declining wild fish stocks, and increasing demand and high cost for fish. Commercial cage culture has been mainly restricted to the culture of higher-value and compound-feed-fed finfish species and more than 80 species presently cultured in cages.

Prior to starting cage aquaculture, several factors need to be considered such as site selection, cage size, material for cage construction, selection of species for culture, stocking density, feed management, etc.

Site selection: -one of the important factors which determine the success and sustainability of cage culture. Criteria that must be considered for site selection are depth of water column, water current, pollution-free area, etc. The depth of the water column required for cage culture varies with resources for example reservoir cage culture requires 5m or more whereas 3m for cage culture in wetlands.

Cage size: - The costs per unit volume decrease with increasing cage size. The size of the cage depends on the species and site selected for culture. The ideal size for a grow-out cage is 6m due to its easy maneuvering and reduced labor.

Material for construction: - Earlier locally available materials were used for the construction of cages such as wood and bamboo for the framework, and empty plastic barrels as floats. Strong and advanced materials like polyvinylidene chloride, galvanized iron pipe, high-density polyethylene, and stainless steel, were used for the sustainability of cages. Netting material used for cage construction includes polyethylene and polyamide. The former one was used for the construction of a nursery and grow-out cage culture and the latter one was used for hapa.

Selection of species: -Factors such as fast growth, high feed conversion ratio, availability of seed, and disease resistance are considered for the selection of species

Stocking density: - Depend on species requirement, operational factors, carrying capacity of the cage and the feeding habits of the cultured species.

Cage aquaculture offers the chance to utilize existing water resources even on a small scale. In addition, other advantages of cage culture include the low carbon footprint, Low operational expenses, possibility of high stocking density, no energy requirement for natural water exchange for cage culture in the lotic ecosystem, and Simplified harvesting. Like other aquaculture technologies cage culture is also affronted by some problems such as the chance of occurrence of pathogens in running water, fast-flowing water may carry the feed that results in loss of feed, more over the biofouling activities over the cage nets and cage frame.

Biofouling In Cage Culture and Its Impacts

Submerged aquaculture cage nets are highly susceptible to biofouling especially during summer months due to favorable and nutrient-rich aquatic environments around the cages which attract micro and macro foulers, and also attract invasive species like *Mytella strata*. Biofouling in aquaculture cages develops either through a succession model or a probabilistic model.Biofouling in aquaculture cage nets causes several problems such as occlusion of mesh openings,thereby increasing weight and drag, deformation of cages due to the ensuing stress, reduction of volume, thereby decreased stocking density per area, anoxic condition due to disruption of dissolved oxygen flow, blocking of food waste diffusion, restriction of water exchange, increased hydrodynamic force, all of which makes an unfavorable environment for fish and which adversely impacted fish health. In addition, cnidarians' biofouling can be harmful to the fish; biofouling can facilitate and amplify the presence of pathogens by harboring viral, bacterial, and parasitic organisms that cause various diseases.

Mitigation Methods for Controlling Biofouling in Cages

Frequent visual inspections of cage nets can catch early signs of biofouling. Gently scrubbing or brushing the net surface can remove accumulated organisms before they become a problem. In situ, net cleaning is one of the most common methods employed by farmers. This proactive approach prevents excessive buildup and maintains optimal water flow. Introducing natural predators like certain fish species and invertebrates into the cage ecosystem can help control biofouling organisms. These natural grazers feed on unwanted growth, reducing the need for manual cleaning. This method encourages a balanced ecosystem within the cage. Periodically moving aquaculture cages to new locations can disrupt the settlement of biofouling organisms. This method prevents attachment and growth on cage surfaces, reducing the overall impact of biofouling. Applying non-toxic anti-fouling coatings to cage nets can deter the attachment of biofouling organisms. These coatings create a slippery surface or release compounds that discourage settlement, making it easier to clean the cages when necessary. Using UV light systems can inhibit the growth of biofouling organisms on cage surfaces. UV treatment disrupts their reproductive cycles and prevents excessive accumulation. This method is environmentally friendly and helps maintain clean cages. Simple mechanical devices, such as rotating brushes or water jets, can be installed on cages to continuously clean the net surfaces. These devices help prevent biofouling buildup and ensure consistent water flow.

Nano Technological Interventions in Cage Aquaculture

The existing In-situ cleaning, rotational movement, and biological control methods have not successfully tackled biofouling problems effectively and sustainably. Therefore, new surface technologies in combination with current methods like the use of nano-engineered particles should be developed by considering ecological effects. Nanotechnology has enormous potential to provide innovative improvements to aquaculture systems to reduce costs, increase efficiency and reduce our impact on the environment. The non-polar nature of polyethylene aquaculture cage net causes difficulties in antifouling strategies over. For minimizing this problem in antifouling coating CIFT introduced copper oxide (CuO) nanoparticles coating over the modifiedsurface of polyethylene by using polyaniline. The small size and high surface activity of nanoparticles rendered them a potential material that can use in cage nets. Nano copper oxide hasthe efficiency to avoid incrustation of microorganisms and hence prevent biofilm formation. The nano CuO-treated cage net exhibited excellent biofouling resistance in the marine environment and the percentage of occlusion of the mesh by foulers was 56.77% more efficient than the untreated cage net. Nanomaterials improve the durability and strength of cage materials by improving the adhesiveness and rheological parameters such as viscosity, elasticity, mechanical strength and plasticity that increases the resistance to corrosion and wear and tear in harshaquatic environment. In addition, Nanomaterial coating reduces the maneuverability and cost of cleaning cage frames and cage nets. The continuously flowing water may carry the leached nanoparticles so the probability of accumulation of nanoparticles (CuO) on cultured species inthe cage is very less. While, nano metal oxide–polymer composites as it exhibits hydrophilicity, large surface area, and high toxicity towards microorganisms all these properties make it an suitable option for managing biofouling in cages.

Conclusion

Cage aquaculture holds promise for meeting the rising demand for affordable nutrition. Biofouling remains a challenge, impacting production and fish health. Novel nanotechnology interventions offer potential solutions, enhancing cage materials, resisting biofouling, enabling disease management, and real-time monitoring. Integrating nanotechnology can foster efficient and sustainable aquaculture, ensuring global food security.

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MICRO AND NANOPLASTICS POLLUTION IN THE MARINEENVIRONMENT

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Introduction

UNEP defined "Marine litter consists of items that have been made or used by people and deliberately discarded into the sea or rivers or on beaches; brought indirectly to the sea with rivers, sewage, storm water or winds; or accidentally lost, including material lost at sea in bad weather". Marine litter is a pressing global concern, with plastics constitutes over 80% of all litter. Plastics encompass a wide range of synthetic or partially synthetic materials that use polymers as their main building blocks with intrinsic flexibility makes it possible to shape solid things with a variety of shapes by molding, extruding, or pressing. This property, along with numerous of other qualities including light weight, durability, adaptability, and cost-effective manufacture, has driven their widespread acceptance. Chemicals made from fossil fuels, particularly natural gas and petroleum, are a major component in modern plastic manufacture. However, recent advancements in industrial methodologies have introduced alternatives manufactured from renewable resources, including derivatives sourced natural materials.

Plastics have become an integral part of modern life and are used in various industries, including packaging, construction, electronics, automotive, healthcare, fishing and more. The production of plastic experienced a remarkable surge, escalating from 2 million tons in 1950 toan astonishing 200 million tons by the year 2020. Notably, 40% of the global plastic output findsapplication in packaging purposes. Most of the packaging purposes use single-use plastics. Single-use plastics do pose significant environmental challenges and have been widely recognized as a major contributor to plastic pollution. Single-use plastics are described as plastic products that are intended to be used just once before being discarded. Due to their affordability, toughness, and adaptability, these polymers are frequently utilised for convenience and packaging. Plastic straws, water bottles, plastic bags, plastic cutlery, and other food packaging materials are all examples of single-use plastics.

In the marine litter, approximately 35% plastic waste materials are denser than seawater which results the sinking of these materials to the seafloor and infiltrating the depths of our oceans. The remaining 65% remains buoyant on the ocean's surface, capable of traversingextensive distances through wind-driven currents. Plastic production and consumption persist at current levels, projections from the UNEP suggest that by 2050, the oceans will contain more plastic (in terms of weight, measured in thousands of tonnes) than fish. Furthermore, UNEP estimates that approximately 99% of seabirds have ingested plastic, underscoring the widespread and concerning impact of plastic pollution on wildlife and marine life.

Different Types of Plastics in the Marine Environment

Polyethylene (PE): This is one of the most widely used plastics. It comes in different forms, such as Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE). LDPE is flexible and used in items like plastic bags and squeeze bottles, while HDPE is stiffer and used for containers, pipes, and toys. HDPE is also used as a webbing material in fishing industry.

Polypropylene (PP): PP is renowned for withstanding heat and chemicals. It is utilized for packaging, automotive components, laboratory equipment, and ropes in the fishing industry.

Polyvinyl Chloride (PVC): PVC is versatile and used in pipes, cables, flooring, and a variety of products. It can be rigid or flexible, depending on additives used during production.

Polystyrene (PS): PS can be found in two main forms: expanded (EPS) and solid. EPS is used in packaging and insulation, while solid PS is used for items like disposable cutlery and CD cases.

Polyethylene Terephthalate (PET): PET is commonly used for beverage bottles and food packaging due to its clarity and resistance to gas and moisture. PET bottles are the most widely recycled plastic in the world.

Polycarbonate (PC): PC is known for its impact resistance and transparency. It's used in items like eyeglass lenses, medical devices, and electronic components.

Acrylonitrile Butadiene Styrene (ABS): ABS is a strong and rigid plastic used in products like toys, automotive parts, and consumer electronics.

Polyamide (PA) or Nylon: Nylon is known for its strength, abrasion resistance, and heat tolerance. It's used in textiles, industrial components, mechanical parts and as webbing materialin fishing industry.

Polyurethane (PU): PU is highly flexible and can range from soft foam to rigid plastics. It's used in furniture, footwear, insulation, and more.

Bioplastics: These are derived from renewable resources like corn and cotton. Compared with fossil-based plastics, bio-based plastics can have a lower carbon footprint and exhibit advantageous materials properties.

Sources of Plastic Debris

There are many different sources of plastic debris, including both human and natural processes. These sources all contribute to the buildup of plastic trash in the environment. One of the main causes of plastic debris is improperly managing the disposal of plastic waste. A significant portion of plastics derived from land and sea based sources like fishing industry, offshore platforms, recreational shipping, household and industrial wastes. Inadequate waste management systems, littering, and a lack of recycling infrastructure led to plastics getting into the environment and polluting rivers, oceans, and even natural landscapes. The widespread usage of single-use plastics is an equally important source of plastic waste. The weight of plastic trash is further increased by items like plastic bottles, bags, straws, and other kinds of packaging that make up a sizeable amount of plastic garbage and have a limited useful life before being discarded. Transport and shipping activities also contribute to the environmental pollution of plastic garbage. Plastic packaging, wrapping, and containers are especially vulnerable to accidental loss or deliberate disposal during transit in marine commerce. Rain, in the form of stormwater runoff and urban runoff, aggravates the problem by removing plastic waste from streets and urban areas, transporting it down storm drains, and ultimately disposing of it in rivers and oceans. Even coastal areas are not immune to plastic debris, often due to the practices of beachgoers, tourists, and recreational activities that leave behind litter. This debris can then be transported into the ocean by tides and currents, posing a direct threat to marine ecosystems. Fishing and maritime activities also play a role in the formation of marine litter which results from abandoned, lost, or discarded fishing gear and abandoned end-of-life boats adding to the accumulation of marine plastic debris. These discarded materials pose serious hazards to marine life. About 20% of the plastics in the marine environment is contributed by the fishing sector.

Plastics from Fishing Sector

a. Plastics from fishing gears

The fishing gear materials made of cotton is very popular before the introduction of synthetic materials like nylon. The cotton materials decompose relatively quickly within 2-3 months and its impacts on marine life is negligible while materials like nylon persist for an astonishingly long time. This advantage of synthetic materials make more popular and acceptable but same time it adversely affected the marine life. Synthetic materials like nylon may take 500 to 600 years to break down. The damaged and discarded synthetic material causes pollution. A significant portion of this pollution is attributed to ALDFG, which encompasses nets, ropes,traps, and other fishing equipment that has been abandoned, lost, or discarded in marine environments. ALDFG is defined by the UNEP as a collection of fishing equipment that has been abandoned or thrown into the water and that continues to trap both targeted marine species and undesired ones, resulting in ghost fishing. Ghost fishing refers to a phenomenon where abandoned, lost, or discarded fishing gear continues to actively capture and entangle marine life in a seemingly never-ending cycle. The discarded fishing gear includes nets, lines, traps, and other equipment, becomes a lethal hazard for marine organisms long after it has been left in the ocean. Ghost fishing poses a grave threat to various marine species, as the ensnared animals can suffer injury, suffocation, or death. This process not only harms the targeted fish but also affects unintended species, disrupting ecosystems and perpetuating a destructive cycle.

b. Plastics from fishing vessels

Fiberglass Reinforced Plastic (FRP) is a boat building composite material which became popular in boat construction since late 1940s as an alternative to traditional materials due to scarcity and cost constraints. FRP boats offer benefits such as corrosion resistance, durability, light weight, and high strength-to-weight ratio, making them suitable for small fishing vessels. FRP is madeby binding glass fibers with a thermosetting plastic resin. Glass fibers are used in the form of glass mat and woven roving to create thick layers, which are bonded together using resin,catalyst, and accelerator. Polyester resins, including biphenolic, ortho and isophthalic resins, make up around 75% of the FRP matrix.

FRP is maintenance-free and has many benefits over typical wood materials. Its sleek finish and light weight help the fishermen to navigate quickly. Earlier FRP was used as a sheathing material for fishing vessels constructed with plywood and wood. But presently many of fishing vessels are constructed with FRP as the primary material. The life span of sheathed vessels is only a life of less than 10 years while boats constructed only with FRP having a life more than 30 years.

As the numbers of boats are increasing disposal became an issue for the ELB (End of Life Boats) FRP fishing boats. Due to lack of recyclability, it became a burden to the owners when it comes to an end of its service life. Because there is no simple way to dispose of plastic ELBs and existing options are quite expensive, it may seem tempting to get rid of the problem by dumping them some place in nature or in the sea. Abandoned or derelict vessels (ADVs) are a sort of maritime debris that are aground, broken apart, submerged, exhibit no signs of maintenance or usage, or are generally deteriorated. Abandoned boats are commonly observed on the foreshores,intertidal flats and reefs, throughout the coast. There is currently no financially viable solutionfor recycling FRP materials used in the hull of ships and boats that are manufactured with thermoset resins. Such composite hull components cannot be formed by melting, rolling, thermal forming, or molding into other usable physical forms. In 2016, London convention and protocol discussed and identified abandoned FRP boats is an environmental threat and to be regulated.

Environmental Interactions of Plastics

a. Weathering Of Plastics: Formation of Micro and Nano Plastics

Weathering is a process that entails the transformation of plastic materials when subjected to various environmental factors, including sunlight, temperature fluctuations, and mechanical forces. This prolonged exposure leads to the gradual breakdown of larger plastic items into smaller fragments. Based on size, these breakdown fragments are classified into Mega (>100mm),Macro (21-100 mm),Meso (5-20 mm) and Micro (<5 mm) plastics and nanoplastics (1 to 1000 nm). Nano & microplastics, produced through weathering, encompass a wide range ofsizes and are more prone to ingestion by various organisms, potentially entering the food chain and accumulating up the ecological hierarchy. The adverse effects extend to human health as microplastics and associated contaminants can infiltrate the food chain through seafood consumption. The IUCN (International Union for Conservation of Nature) has documented that South Asia, including India, is discharging 274,000 metric tonnes of primary microplastics into the ocean. On a global scale, the yearly average release of primary microplastics into the ocean isestimated to be 1.5 million metric tonnes. Notably, research conducted by IIT Mumbai has revealed the presence of microplastics even in sea salt sourced from Indian waters.

Microplastic can further undergo weathering to form nano plastics. Nanoplastics refer to extremely small plastic particles that have dimensions in the nanometer range, typically ranging from 1 to 1000 nanometers in size. These particles are even smaller than microplastics and are a subset of the broader category of plastic pollution. Because of their tiny size, nanoplastics have unique properties and behaviors that differentiate them from larger plastic particles. They have a higher surface area relative to their volume, which can lead to increased interactions with other substances in the environment, including chemicals and pollutants. This characteristic makes nanoplastics potentially more chemically reactive and capable of adsorbing or carrying pollutants from the surrounding environment.

They may spread out quickly in a variety of habitats, including soil, water, and the air thanks to their tiny size. Nanoplastics may take on a variety of shapes, from spherical to asymmetrical, which impacts how they interact with the environment and living things. They demonstrate higher mobility and bioavailability due to their large surface area compared to volume, which might cause them to enter the food chain and have an impact on diverse creatures. Their potentialtoxicity, ecological effects, and function as carriers of pollutants are still being studied. Regulations and more research are essential to address the possible dangers of nanoplastics and reduce their prevalence in the environment since they are a growing problem.

b. Leaching Of Plastics

Leaching refers to the release of chemical additives present in plastics into the surroundings, often triggered by interactions with water or other solvents. Plastic products, including single-useitems and larger plastic structures, often contain various chemical additives to enhance their properties, such as flexibility, flame resistance, or color stability. These additives can include plasticizers, stabilizers, flame retardants, and pigments. When plastic items degrade or interact with their environment, either through weathering, mechanical stress, or exposure to different temperatures, these additives can gradually leach out into the surrounding environment.

In aquatic environments, leaching can occur when plastic items like bottles, packaging, or microplastics come into contact with water. As water interacts with the plastic surface, it can dissolve and carry away the additives, potentially releasing them into the water. This process can lead to the contamination of water bodies with these chemical compounds, raising concerns about their impact on aquatic life and ecosystems.Leaching can also be relevant in the context of landfill sites where plastic waste is disposed of. Rainwater or other liquids can percolate through landfills, causing the leaching of chemicals from the decomposing plastics and potentially contaminating groundwater.

Plastics may survive for decades or even centuries because of their strength and resistance to degradation. This persistence can lead to various ecological and environmental issues includes

Impacts on Flora and fauna

Animals can mistake plastic items for food or become entangled in plastic debris. Ingesting plastics can lead to choking, internal injuries, and even death. This is a significant concern for marine life, birds, and other animals.

Ecotoxicity

Plastics can contain additives and chemicals that are toxic to both wildlife and humans. These toxins can leach into the environment, posing a threat to aquatic ecosystems and the organisms living in them.

Habitat Degradation

Accumulations of plastic waste can alter natural habitats, disrupt ecosystems, and damage fragile environments like coral reefs and coastal areas.

Aesthetic Impacts

Plastic pollution can tarnish the beauty of landscapes and water bodies, affecting tourism and recreational activities. Cleanup efforts also incur significant costs.

Social And Livelihood Impacts

Plastic pollution raises the issue by encroaching upon the spaces traditionally used for fish landing and various related activities. As plastic waste accumulates along coastlines, beaches,and water bodies, it diminishes the available area for fishing operations, processing, and other essential tasks. This not only disrupts the livelihoods of fishing communities but also hampersthe overall efficiency of the fisheries industry.

Mitigation Initiatives for Fishing Plastics

Addressing environmental concerns related to fishing gear and boat disposal requires a different approach. These include the implementation of stringent gear regulations, marking for easy tracking and identification, to enhance responsible fishing practices. Encouraging the adoption of biodegradable materials for fishing material construction contributes to reducing environmental impacts. Additionally, the proper disposal of fishing materials including end-of-life Fiberglass Reinforced Plastic (FRP) fishing boats necessitates the establishment of clear guidelines. Ensuring the construction of FRP fishing boats adheres to set standards is essential for long-term sustainability. Creating awareness within the fishing community can be achieved through seminars, symposiums, and field demonstrations. Incentive-based programs for litter collection by fishers, as well as promoting recycling options, provide practical ways to combat pollution. Initiatives like the "SuchitwaSagaram", a Kerala government project which aimed for the eradication of plastics from the sea, further contribute to effective waste management in coastal areas, collectively driving the pursuit of a more environmentally conscious fishing industry.

The 6Rs represent a set of principles aimed at promoting sustainable and responsible consumption and waste management in the case of plastics. Each "R" stands for a different action that individuals and communities can take to minimize their environmental impact.

Rethink: Reevaluating our consumption habits and considering the environmental and social consequences of our choices.

Refuse: The "refuse" principle encourages saying no to products or items that are unnecessary or harmful to the environment. This can include refusing single-use plastics, excessive packaging, and other items that contribute to waste.

Reduce: This principle promotes the idea of consuming less and minimizing our overall consumption. By using resources more efficiently and avoiding overconsumption, we can reduce our ecological footprint.

Reuse: Reusing involves finding ways to use items again instead of throwing them away after a single use. This can include using durable containers, repairing and repurposing items, and participating in activities like thrift shopping.

Recycle: Recycling involves the proper sorting and processing of materials to create new products from old ones.

Repair: Repairing items instead of discarding them helps extend their lifespan and reduces the demand for new products. This contributes to a more circular economy where items are used for as long as possible before being recycled or disposed of.

It's important to note that addressing plastic pollution requires global cooperation and individual actions to reduce plastic consumption and improve waste management practices.

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CIFT INITIATIVES UTILISING NANOTECHNOLOGY

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Introduction

In the relentless pursuit of sustainable advancements in marine industries, the Central Institute of Fisheries Technology (CIFT) has taken a pioneering stride by harnessing the power of nanotechnology to address the critical challenge of marine material deterioration. As the maritime world faces the corrosive forces of saltwater, extreme weather conditions, and relentless wear, CIFT's groundbreaking initiative emerges as a beacon of innovation. By fusing the realms of marine science and nanotechnology, this initiative endeavours to unlock novel solutions that not only enhance the longevity of marine materials but also revolutionize the marine sector's approach to combating degradation. In this exploration, we delve into CIFT's bold endeavour, unravelling how the integration of nanotechnology promises to reshape the landscape of marine material preservation and drive sustainable progress forward.

In 2007 Ashraf et al. developed a novel technique for preventing corrosion in marine environments by reinforcing aluminium with cerium oxide (CeO2). Corrosion of aluminium in aggressive marine environments is a significant concern due to its detrimental effects on structural integrity and performance. Traditional methods of using cerium ions for surface modification have shown limited effectiveness in such environments. To address this challenge, the researchers turned to metal matrix composites of aluminium, leveraging the benefits of aluminium's density, strength, ductility, and cost. By incorporating cerium oxide nanoparticles into the aluminuim matrix, the researchers achieved remarkable results in suppressing corrosion in saline environments.

Key achievements and highlights of the study include:

Effective Corrosion Suppression: The incorporation of cerium oxide nanoparticles into the aluminum matrix led to a significant reduction in corrosion rates when exposed to aggressive marine environments. This outcome demonstrates the potential of cerium oxide as a corrosion-resistant material.

Aluminum Oxide Formation Control: Unlike traditional methods that might lead to the formation of aluminium oxide (Al_2O_3) which can contribute to pitting corrosion, the presence of cerium oxide nanoparticles in the matrix did not facilitate the premature formation of aluminium oxide. This is a critical achievement, as pitting corrosion can be particularly destructive in marine environments.

Long-Term Stability: The research findings suggest that the protective effects of the cerium oxide-reinforced aluminium matrix remain stable over time, with no indication of potential re shift or deterioration due to the onset of pitting. This long-term stability is a testament to the effectiveness of the proposed technique.

Nanotechnology Application: The study showcases the successful utilization of nanotechnology by incorporating cerium oxide nanoparticles into the aluminium matrix. Nanoparticles offer enhanced material properties and surface interactions, contributing to the overall success of the corrosion prevention technique.

By leveraging the advantages of aluminium and cerium oxide nanoparticles, the study demonstrates a promising solution for extending the lifespan and maintaining the performance of aluminium structures exposed to aggressive conditions. This achievement not only underscores the potential of cerium oxide but also highlights the power of nanotechnology in addressing real-world challenges.

Total volatile basic nitrogen (TVBN) is a critical parameter for assessing fish spoilage and adulteration. Ashraf et al. 2015 developed **nanotechnology-enabled sensor development for the efficient detection of Total volatile basic nitrogen (TVBN) molecules**. The study highlights the creation of a novel polyaniline-curcumin-copper-cobalt hybrid composite and its capabilities as a sensitive and versatile sensor:

Challenging Detection Problem Addressed: Detecting fish spoilage and adulteration is a complex issue that has implications for both consumers and traders. This research addresses this challenge by developing an innovative sensor capable of detecting TVBN content, which serves as a reliable indicator of fish spoilage.

Hybrid Composite Synthesis: The researchers synthesized a polyaniline-curcumin-copper-cobalt hybrid composite as the sensing material. This hybrid composite was carefully designed to exhibit enhanced sensitivity and selectivity towards TVBN molecules, showcasing the potential of nanotechnology in sensor development.

Versatile Sensing Responses: The hybrid composite demonstrated excellent sensing responses to a range of volatile amines, including ammonia and mono-, di-, and trimethyl amines. The responses were evaluated using visual observations, spectroscopic analyses, and electrochemical methods, showcasing the hybrid's versatility in detecting various TVBN molecules.

Electrochemical Analysis: The cyclic voltammetric and electrochemical impedance responses of the composite to TVBN displayed a strong linear relationship between concentration and current or impedance. This indicates the composite's efficacy in accurately quantifying TVBN concentrations.

Unique Sensing Behavior: The composite exhibited unique cyclic voltammetric response behavior for dimethyl amine, where the current decreased with increasing concentration. This distinct behavior adds to the composite's capabilities in differentiating between individual TVBN content.

Potential Applications: The study suggests that the composite has the potential to be used in strip sensors, electronic devices, quantitative analytical reagents, and TVBN odor absorbers. The

synergy between the spatial sp3 π electron cloud from the organic component and the partially filled d orbital electron from the metals enhances the sensing response.
Successful synthesis and utilization of a polyaniline-curcumin-copper-cobalt hybrid composite as a sensitive and versatile sensor for detecting TVBN molecules were achieved by the research group. This achievement underscores the capabilities of nanotechnology in creating innovative sensing solutions for real-world challenges, particularly in the field of food quality assessment and safety.

Netting materials in cage aquaculture are prone to biofouling, leading to the clogging of mesh openings. Biofouling negatively affects the efficiency and hygiene of the aquaculture operation. In 2016 Ashraf et al**,** addresses this challenge by proposing an antifouling solution.
The research presents a significant advancement in addressing the issue of biofouling in cage fishing nets used in aquaculture. The study focuses on the development of an innovative antifouling coating using nano copper oxide incorporated polyethylene glycol (PEG)hydrogel, utilizing nanotechnology to combat fouling and enhance aquaculture net performance
In Situ Synthesis: The researchers employed a microwave-assisted in situ synthesis approach to create a hydrogel by incorporating nano copper oxide particles into a polyethylene glycol methacrylate-based matrix. This unique approach leverages nanotechnology to modify the properties of the hydrogel, enhancing its antifouling potential.
Outstanding Antifouling Performance: The hydrogel reinforced with 0.004% (wt/vol) copper oxide-treated netting material demonstrated exceptional resistance to fouling. When exposed to an estuarine environment for 90 days, this composite displayed the lowest biomass accumulation.The presence of copper oxide in the matrix, combined with the hydrophilic nature of thehydrogel, effectively deterred biofilm formation and attachment of fouling organisms to thenylon material.
Nanotechnology's Role: The research underscores the pivotal role of nanotechnology in creating a composite material that effectively addresses the biofouling challenge. The incorporation of nano copper oxide and the utilization of hydrogel technology synergistically offer a promising solution to prevent fouling in aquaculture cage nets.
Researchers successfully fabricated a technique to mitigate biofouling in cage fishing netsthrough the development of a novel antifouling composite material. By harnessing nanotechnology, they successfully integrated nano copper oxide and hydrogel technology to create a highly effective solution for preventing fouling in aquaculture cage nets. This achievement highlights the potential of nanotechnology-driven innovations to address real-world challenges and enhance the sustainability of aquaculture operations.

Sarkar et al, 2018 presents a remarkable advancement in nanotechnology-enabled sensor development for the sensitive detection of volatile amines. **The study focuses on the utilization of calixarene-functionalized single-walled carbon nanotubes (SWCNTs) for enhanced detection capabilities:**

Calixarene Functionalization: The researchers achieved the formation of a hybrid material by noncovalent functionalization of SWCNTs with calixarene using a solvent casting technique. This innovative approach enhances the sensitivity and selectivity of SWCNTs in detectingvolatile amines.

Enhanced Detection: The hybrid SWCNT-calixarene material exhibited sensitive detection capabilities for volatile amines at room temperature. The results demonstrated remarkable sensitivity levels, achieving detection down to 1 ppm concentrations for various test analytes, including NH3, TMA, and DMA (TVBs), with sensor sensitivity ranging from 4.1% to 7.4% per ppm.

Low Limit of Detection: The limit of detection (LOD) for the hybrid material was found to be impressively low, approximately 0.6 ppm for NH3, 0.3 ppm for TMA, and 0.4 ppm for DMA. These values indicate the high sensitivity and reliability of the sensor.

Electrostatic Gating Effect: The field-effect transistor (FET) analyses provided insights into the sensing mechanism of the SWCNT-calixarene hybrid. The dominant sensing mechanism was attributed to the electrostatic gating effect, indicating the hybrid's ability to respond to changes in the electrical properties upon exposure to analytes.

Electronic Nose Applications: The research highlights the potential for developing sensorarrays based solely on calixarene-functionalized SWCNTs. The versatility of calixarene compounds offers opportunities for creating a range of sensor configurations for electronic nose applications, enabling the identification and differentiation of various analytes.

They display the successful utilization of nanotechnology in creating a highly sensitive sensorfor the detection of volatile amines. The functionalization of SWCNTs with calixarene demonstrates improved sensor performance, low limit of detection, and a potential pathway toward electronic nose applications. This achievement underscores the capabilities of nanotechnology to revolutionize sensor technologies and address real-world challenges in areas such as environmental monitoring and quality control.

Ahana *et a*l, 2019 introduces the use of **nano silicon dioxide reinforced mixed-charged zwitterionic hydrogel to combat biofouling**, emphasizing notable achievements:

Biofouling Management Challenge: Biofouling is a critical issue in aquaculture cages, impacting productivity and requiring substantial resources for management. This research focuses on addressing this challenge through the development of an effective antifouling agent.

Zwitterionic Hydrogel: The study employs a super hydrophilic pseudo zwitterionic hydrogel

Nano Silicon Dioxide Reinforcement: The hydrogel is further enhanced with nano silicon dioxide reinforcement, enhancing its antifouling properties and overall performance in aquaculture cage nets.

Synthesis and Application: The study synthesizes the nano silicon oxide reinforced zwitterionic hydrogel over polyethylene aquaculture cage nets coated with polyaniline using a situ microwave reaction. The coated nets are subjected to testing for their biofouling resistance.

Effective Inhibition of Fouling: The results of the study demonstrate the successful formation of stable coatings over the nets, with four different treatments effectively inhibiting fouling compared to untreated nets. This highlights the potential of the coated nets to combat biofouling.
Field Immersion Testing: Six months of immersion of the treated nets in estuarine environments revealed the significant biofouling inhibition capability of the nano silicon oxide reinforced zwitterionic hydrogel-coated polyethylene nets. While not meeting industrial standards, the treated nets demonstrated reduced fouling by hard-shelled organisms compared to untreated controls.
Hydrogel Characteristics: The mixed-charged zwitterionic hydrogel reinforced with nanosilicon oxide exhibited a medium hydrophilic nature, contributing to its antifouling capabilities. The work by Ahana et al, demonstrates a promising utilization of nanotechnology byincorporating nano silicon dioxide reinforced mixed-charged zwitterionic hydrogel for biofouling control in aquaculture cage nets. This achievement underscores the potential ofnanotechnology to address practical challenges and enhance sustainability in various industries,including aquaculture.

In 2020 the research conducted by Keerthana et al, presents a notable breakthrough in utilizing nanotechnology for **corrosion inhibition in boat-building carbon steel (BIS 2062) by synthesizing carbon nanodots (CDs) from chitosan.** The study emphasizes the significant achievements made through the utilization of nanotechnology and CDs as an innovative corrosion inhibitor:
Carbon Nanodot Synthesis from Chitosan: The study successfully synthesized carbon nanodots (CDs) from chitosan, showcasing a novel approach to creating fluorescent nanoparticles with unique properties. CDs have attributes such as environmental friendliness, high conductivity, low toxicity, and high stability, making them an attractive option for various applications, including corrosion inhibition.
Corrosion Inhibition Performance: The CDs were applied as a coating on BIS 2062 carbon steel, commonly used in boat-building. The electrochemical characteristics of the coated steel were evaluated using techniques such as linear sweep voltammetry (LSV) and electrochemical impedance spectroscopy (EIS). The results demonstrated that steel coated with 0.05% CD exhibited excellent corrosion resistance, indicating the potential of CDs as effective corrosion inhibitors.
Suppression of Iron Oxide Oxidation and Reduction: The cyclic voltammetric evaluation using a glassy carbon electrode revealed that the oxidation and reduction potential of iron oxide were significantly suppressed due to the presence of CD coating. This observation highlights the CDs' capability to interfere with the corrosion process and protect the metal surface.
Potential Alternative to Graphene-based Materials: The study positions CDs as a promising alternative to graphene-based materials for corrosion inhibition. This innovation offers a more environmentally friendly and efficient solution for combating corrosion, with CDs' distinct properties enhancing their potential effectiveness.

Successful synthesis of carbon nanodots from chitosan and applying them as a corrosion inhibitor for boat-building carbon steel. The incorporation of CDs demonstrates their potential to effectively inhibit corrosion, enhance material protection, and offer an alternative to conventional corrosion prevention methods. This achievement underscores the power of nanotechnology in addressing real-world challenges and advancing the field of materials protection in various industries.

The research conducted by Ashraf *et al*, 2020 presents a groundbreaking approach in addressing the issue of biofouling in cage aquaculture nettings. **The study introduces an innovative method of using polyaniline and nano copper oxide to develop biofouling- resistant polyethylene cage nettings.** The incorporation of nanotechnology in this context offerssignificant achievements:

Biofouling Challenge: Biofouling in cage aquaculture netting leads to a range of problems, including clogging of mesh openings, increased stress on the netting, and hindered fish growth. This paper tackles these challenges by proposing a novel method to prevent biofouling.

In-Situ Synthesis of Polyaniline: The researchers employed an in-situ synthesis technique to coat the polyethylene cage netting material with polyaniline. This approach allows the integration of the conducting polymer directly onto the netting, enhancing its properties and performance.

Nano Copper Oxide Treatment: The modified netting material was subsequently treated with nano copper oxide. The combination of polyaniline and nano copper oxide creates a synergistic effect to combat biofouling more effectively.

Fouling Resistance in Estuarine Environment: The modified netting material was exposed to an estuarine environment, and the results revealed excellent fouling resistance. This achievement demonstrates the potential of the developed method to significantly reduce biofouling-related issues in cage aquaculture.

Nanotechnology's Role: The integration of nanotechnology, specifically the use of polyaniline and nano copper oxide, played a crucial role in achieving the desired results. Nanotechnology allows for precise modification and enhancement of material properties, leading to improved performance.

They introduces a novel method for addressing biofouling in cage aquaculture nettings byutilizing polyaniline and nano copper oxide. The application of these nanomaterials presents a promising solution to prevent biofouling-related issues, ultimately enhancing the efficiency and sustainability of aquaculture operations. This achievement underscores the potential of nanotechnology-driven innovations in solving real-world challenges and advancing various industries, including aquaculture.

Ashraf et al, 2021 researched on **utilization of nanotechnology in a sustainable process for the co-synthesis of nano carbon dots, nano hydroxyapatite, nano β-dicalcium diphosphate,**

and a nano carbon dot-hydroxyapatite composite from fish scales. The study emphasizes the following significant accomplishments:

Challenges of Conventional Extraction: Traditional methods for obtaining biological hydroxyapatite involve harsh chemical treatments to remove organic material, which often compromises the purity and crystalline nature of the resulting hydroxyapatite. The study addresses these limitations by proposing an innovative and sustainable approach.

Simultaneous Synthesis of Multiple Nano Products: The study introduces a process to simultaneously synthesize four high-value nano products from fish scales—nano carbon dots, nano hydroxyapatite, nano β-dicalcium diphosphate, and a nano carbon dot-hydroxyapatite composite. This approach optimizes resource utilization and minimizes waste.

Hydrothermal Conversion of Organic Matter: The organic matter in fish scales is converted into nano carbon dots using a hydrothermal process with acetic acid. The acetic acid serves as a medium to release mineral-organic linkages and hydrolyze collagenous proteins linked with calcium phosphate, resulting in both fluorescent nano carbon dots and mineral residue.

Formation of Hydroxyapatite and Dicalcium Diphosphate: The mineral residue is then transformed into hydroxyapatite through a sintering protocol. Additionally, β-dicalcium diphosphate is attached to carbon dots, followed by crystallization and high-temperature sintering.

Synthesis of Composite Materials: The study also presents the synthesis of a hydroxyapatite-carbon dot composite using a hydrothermal method. The spectral and morphological analyses demonstrate strong interaction between carbon dots and hydroxyapatite in the composite.

Sustainable Utilization of Fish Scales: The proposed method offers a sustainable and environmentally friendly approach to fully utilize fish scales, converting them into valuable nano products. This sustainable process demonstrates the potential to transform waste materials into valuable resources.

The study demonstrated the co-synthesis of multiple valuable nano products from fish scales. This achievement not only showcases the potential of nanotechnology for resource utilization butalso emphasizes its role in advancing sustainable practices and minimizing waste in various industries.

Ashraf et al, 2023 conducted a research displaying a pioneering achievement by utilizing nanotechnology for a **green extraction process of nanocarbon dots (CDs) from prawn shells, and subsequently incorporating these CDs into epoxy polymers for corrosion-resistant coatings**. The study emphasizes the significant accomplishments achieved through this innovative approach:

Utilization of Waste Materials: The study focuses on the exoskeletons of prawn, shrimp, and crab, which are often discarded as waste. These exoskeletons contain valuable inorganic and organic constituents. The research highlights the importance of recovering not only chitin but also other organic components from these discarded materials.

Nanocarbon Dot Synthesis: The researchers successfully synthesized nanocarbon dots using a hydrothermal carbonization process. This eco-friendly method leverages the waste materials to produce valuable nanomaterials with unique properties.

Corrosion Resistance Enhancement: The epoxy polymer composite coated over the steel surface exhibited improved corrosion resistance. This outcome underscores the potential of nanocarbon dots as effective additives to enhance the protective properties of polymer coatings.

Interaction with Polymer Matrix: The chemical and morphological data of the epoxy polymer composite revealed the interaction between the nanocarbon dots and the polymer matrix. Specifically, the presence of NH_2 functional groups in the nanocarbon dots synergistically acted with the hardener to create a pore-free epoxy coating.

Dual Product Extraction: The study not only synthesized nanocarbon dots but also extracted chitin from the prawn shell using the hydrothermal process. This dual-product extraction showcases the economic and environmental benefits of the proposed green synthesis protocol.

Researchers demonstrates the successful utilization of nanotechnology for the green extraction of nanocarbon dots and chitin from prawn shells. The incorporation of nanocarbon dots into epoxy polymers for corrosion-resistant coatings underscores their potential to enhance material properties and performance. This achievement highlights the power of nanotechnology-driven innovations in transforming waste materials into valuable products with diverse applications, contributing to both economic and environmental sustainability.

Conclusion

Through the ingenious fusion of nanotechnology and marine science, CIFT's pioneering efforts offer a promising pathway to overcome the formidable challenges posed by the harsh marine environment. By extending the lifespan of marine materials and introducing novel approaches to counter degradation, this initiative not only showcases the power of interdisciplinarycollaboration but also sets a precedent for the transformative potential of technology in achievinga more resilient and sustainable maritime future. As we delve deeper into the unfolding chapters of CIFT's groundbreaking endeavor, we anticipate witnessing the emergence of novel solutions that will undoubtedly leave a lasting impact on the marine sector and the world at large.

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