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Research Article

Nanoparticles: Concept, Types and Applications in Engineering Technology (Water Treatment, Energy Production and Biomedical Technology)

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ABSTRACT

Nanoparticles are particles that differ from other particles due to their size and stability. Their size is in the range 1-100 nm, depending on the particular type of nanoparticle. Nanoparticles are particularly designed on the basis of certain characteristics, such as mobility and compact surfaces. There are different types of nanoparticles depending on the size, property, and delivery. Carbon-based nanoparticles are highly specific at an industrial level for the preparation of tubes and pipes using the nanoparticles. Lipid-based nanoparticles have been used as a carrier in technological processes and biomedical applications where the specific layer of lipids could be designed in order to deliver the nanoparticles comprising the lipid layer to perform their function as the specific level. Gold nanoparticles are designed due to their chemical as well as optical characteristics. These nanoparticles have applications in the identification of proteins using optical specificity as well as light-based detection of molecules in which light scattering, reflection mechanisms are involved. Nanotechnology has important applications in the fields of medical and biomedical engineering. Nanotechnology is one of the diverse fields in engineering and technology for the production of fuels from different materials as raw sources of petroleum, to improve the catalysis. Carbon nanotubes have gained much attention for their use as a wastewater and water filter.

***Keywords*:** Nanoparticles, Water treatment, Energy production, Biomedical engineering approach

INTRODUCTION

Nanoparticles are particles that differ from other particles due to their size and stability (Ulfat et al., 2020; Rahim et al., 2020]. Their size ranges from 1 to 100 nm, depending on the specific type of nanoparticle. There are different types of nanoparticles designed to advance water treatment by removing toxic metals from wastewater, and they have significant applications in the medical field as well as in energy production using specialized carriers. They also have applications in engineering, such as in nano-based batteries, which help generate electricity (Bai et al., 2020).

Nanoparticles are specifically designed based on certain characteristics, such as mobility and compact surfaces. The atoms on the inner surfaces can easily move from one place to another due to their high mobility (Kalimuthu et al., 2020). They have compact surfaces to ensure delivery in the correct direction with proper orientation. Once the designed nanoparticles reach the proper destination, they start performing their functions effectively. Traditional particles used to remove heavy metals from wastewater required a lot of heavy machinery and were therefore costly in today's context. As a result, nanoparticles have become more efficient in delivery systems and various aspects of treatment in technological processes (Ruoff et al., 1993; Xu et al., 2011).

Nanoparticles are useful for detecting biological molecules because of their strong binding with high affinity, which helps in imaging and molecular engineering. Traditional methods are less effective compared to nanoparticle-based detection (Oh et al., 2010). They are often costly and unstable, while nano-based approaches are low-cost and offer stable compatibility with targeted materials. Therefore, nanotechnology is valuable in engineering, molecular targeting, biological delivery, and imaging due to its efficient and compact binding with both living and non-living materials (Hou et al., 2020). Various techniques are used to detect nanoparticles at the micro level for accurate measurement because of their high specificity. Some of these include electron microscopy, infrared microscopy, and scanning microscopy. While these techniques are effective in measuring the size and concentrations of matrices, they are more expensive than standard methods because they require extensive sample preparation and reagents for quantification to ensure reliable accuracy in analyzing specific nanoparticles (Francia et al., 2020).

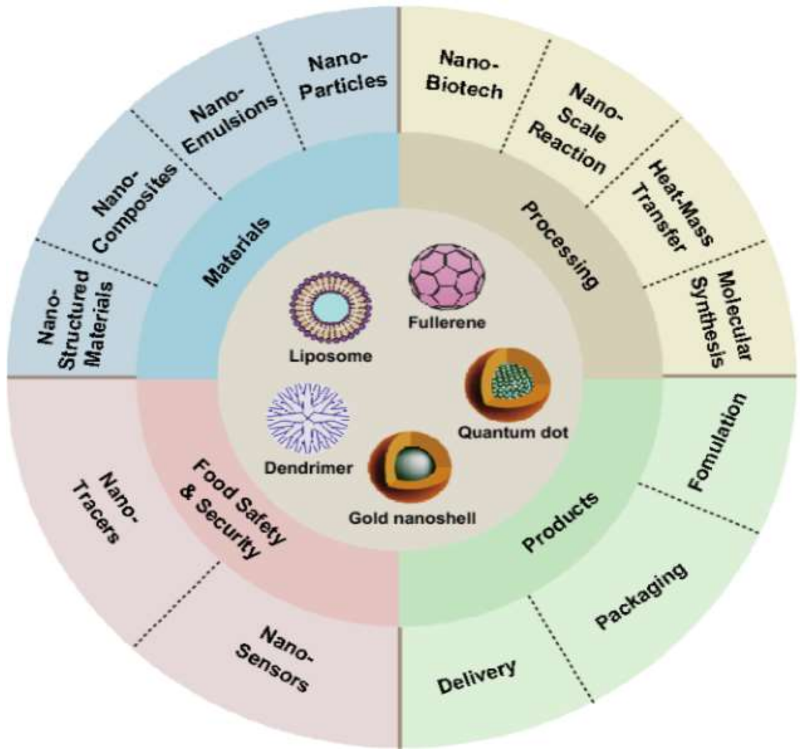

Fig 1: Different types of nano-particles and their specifications.

Types of Nanoparticles

There are the following types of nanoparticles depending on the size, property and delivery system, as shown in Fig. 1.

1. Carbon-Based Nanoparticles
2. Liposome-Based Nanoparticles
3. Gold Nanoparticles

1. Carbon-Based Nanoparticles

These are the most important nanoparticles made from special tubes of carbon-based particles to ensure the specificity and reliability of delivery systems. These nanoparticles are highly specific at the industrial level for the production of tubes and pipes using nanoparticles. They are divided into two categories depending on the nature of the carbon particles (Rizwanullah et al., 2020).

- Carbon-based nanotubes
- Fullerene-based carbon nanoparticles

Carbon-based Nanotubes

These are the major types of nanoparticles that roll up into tube shapes, giving them a compact form (Samaridou et al., 2020). This arrangement results in strong interactions between the nanoparticles and carbon material, making them stronger compared to other steel- and plastic-based materials due to their high rigidity. These nanoparticles also exhibit other characteristics such as high optical density and electrical conductivity, allowing materials to easily flow to the main targeted system for applications like heavy metal removal in water or biomedical processes (Roco et al., 2011).

Fullerenes-based carbon nanoparticles

These types of nanoparticles form the entire structure of specific nanoparticles designed for water treatment and especially in biomedical applications (Mirzaei, 2020). They create large cavities by adding the right kinds of carbon atoms in specific directions for delivery systems. It ultimately appears as foot-like nanoparticles that offer specific resistance to heat as well as electrical resistance compared to other nanoparticles. These types of nanoparticles are expressly designed for commercial applications and technical processes occurring at an industrial scale (Roco, 2007; Usman et al., 2020).

2. Liposome-based nanoparticles

These nanoparticles have been used as carriers in technological processes and biomedical applications where a specific layer of lipids can be designed to deliver the nanoparticles with the lipid layer to perform their function at a specific level (Zhou et al., 2020). Lipid molecules tightly bind to the layers of nanoparticles as well as solid surfaces of machines for delivery. These nanoparticles are designed for delivery systems to evaluate the status of infectious diseases, where lipids and lipid-based components play a significant role, thus reducing the risks of diseases (Hou et al., 2020; Bayda et al., 2020).

Gold Nanoparticles

Gold nanoparticles are designed for their chemical and optical characteristics. These nanoparticles are particularly involved in absorbing light, which causes light in specific directions to fall on electrons that move from one orbital to a specific other orbital (Oroojalian et al., 2020). These properties make gold nanoparticles effective in diagnosis and in measuring the concentration of analytes in samples. They have applications in protein identification using optical specificity and light-based detection of molecules, involving light scattering and reflection mechanisms. Therefore, these nanoparticles are especially designed for light-based detection, biomedical applications, and in technology for the development of light-based instruments, components, parts, and optical properties (Zahedi et al., 2020; Ma & Liu, 2020).

3. Biomedical engineering and technological Applications

Nanotechnology has significant applications in the fields of medical and biomedical engineering. This field specifically designs nanoparticles for delivering drugs and other pharmaceutical products, thereby helping to reduce the risks of diseases. Nanotechnology utilizes small-sized nanoparticles for detecting diseases at the cellular level (Naqvi et al., 2020). Many drugs, such as nanomedicines, have been synthesized through nanotechnology applications. It helps detect cancer cells, which differentiate from other cells due to the specific binding of nanoparticles to cancer cells, forming a complex that aids early disease diagnosis. Nanoparticles are used to deliver specific drugs to areas where larger particles cannot reach. Overall, nanoparticles are the most efficient in delivering drugs to targeted cells (Salamanca-Buentello & Daar, 2021; Mauter et al., 2018).

Energy Applications

Nanotechnology is one of the diverse fields in engineering and technology aimed at producing fuels from various raw materials, such as petroleum, to improve catalysis (Hodges et al., 2018; Jassby et al., 2018). This field is designed to reduce fuel consumption in power plants and electrical vehicles through combustion. It primarily involves using nanoparticles in sufficient amounts to generate electrical energy. Additionally, it increases engine efficiency through electrical combustion. Nanotechnology can address the shortage of fossil fuels, like diesel and gasoline, by making the production of fuels from low-grade raw materials more economical (Pranjali et al., 2013; Dangroo et al., 2021).

The demand for energy is increasing daily due to higher utilization of electrical power. There are various sources for energy production. Traditional methods often incur higher costs and are less efficient. Energy production can be optimized using nanoparticle technology, which is considered the most reliable and convenient in the modern era (Taran et al., 2021). These nanomaterials are produced at low cost and cause no environmental pollution compared to other methods of energy storage and conservation. Nanotechnology is increasingly applied in traditional energy sources and significantly enhances alternative energy approaches to meet the world's rising energy demands (Wang & Wu, 2012; Muthukrishnan, 2021). Scientists are primarily focusing on the production of energy through different methods, driven by various criteria and advancements in the field.

- Clean
- Affordable
- Renewable energy sources
- Reduce energy consumption
- lessen toxicity
- No environmental pollution

Commonly used Nanomaterials in energy Production

Silicon-based nano semiconductors have the most useful application in solar energy (Sharma, 2021; Oh et al., 2021). These become the most reliable and trustworthy for efficient energy production. Nanocellulose-based mesoporous structures, flexible thin films, fibers, and networks are developed and used in photovoltaic (PV) devices, energy storage systems, mechanical energy harvesters, and catalyst components. They include different parts using nanoparticles through an engineering approach. Incorporating nanocellulose into these energy-related devices significantly increases the use of eco-friendly materials and is very promising for addressing environmental concerns. Furthermore, cellulose demonstrates low cost and large-scale potential (Li et al., 2021; Wu et al., 2021).

Nanotechnology has made significant contributions to energy production at both small and industrial scales. The global market for nanoscale materials, such as nano powders, nanocomposites, nanoscale thin films, and other products, as well as devices like nano sensors, is used in renewable and non-renewable energy generation, including petroleum refining, solar energy, and energy storage methods like batteries and fuel cells as shown in Fig. 2. In other applications, such as energy transmission, energy conversion, and end-use applications, nanotechnology consumption remains negligible (Khamhaengpol et al., 2021; Chen, 2021).

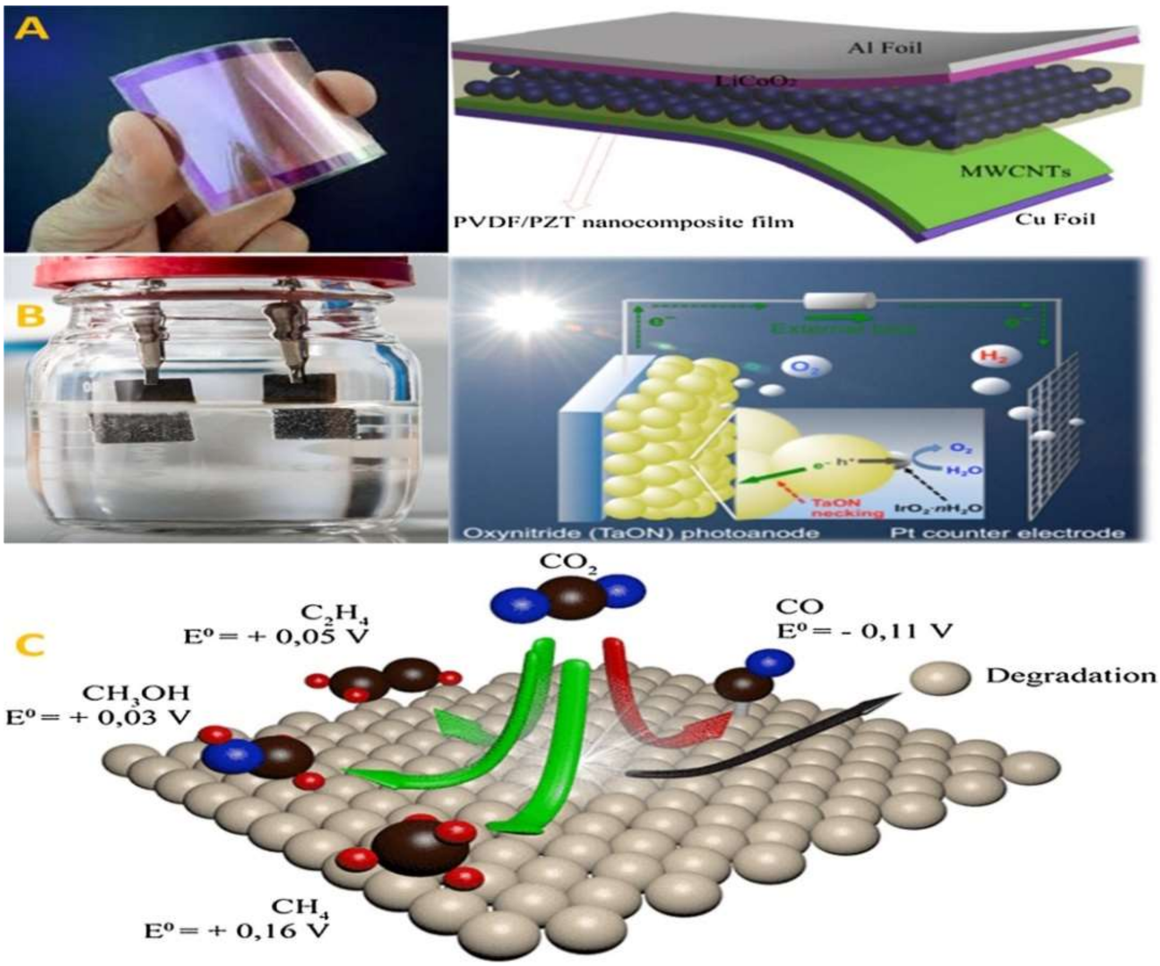

Fig 2: Practical applications of nano-particles in energy harvesting.

Nanoparticles in Water Treatment

One of the best and ideal approaches for testing and removing different types of water contaminants in water using nanotechnology. Nanotechnology can help meet the need for affordable, clean drinking water through rapid, low-cost detection and treatment of impurities in water. Many methods are available for removing toxic metals from water, such as boiling and primarily filtration, which are considered most reliable at the industrial level (Xie et al., 2021; Murshid et al., 2021)).

Water treatment can be achieved using nanoparticles through an integrated approach. There are many heavy metals in water that need to be removed, such as nickel, chromium, lead, and arsenic. These metals can cause serious damage to brain cells and often lead to brain hemorrhages. Toxic metals damage different parts of the body, leading to severe diseases related to water pollution. Nanoparticles are designed to remove toxic metals from water, making them helpful for water treatment. Carbon nanotubes have gained much attention for their use in wastewater and water filtering. These carbon-based nanotubes are mainly used in industries due to their low cost and efficient water removal process. In the case of CNT-based ultrafilters modified with electrochemistry, energy consumption is reduced by twofold compared to unmodified CNT-based filters. Therefore, these carbon-based nanotubes are valuable in nanotechnology as well as in water treatment as shown in Fig.3 (Han et al., 2021; Hart, 2021).

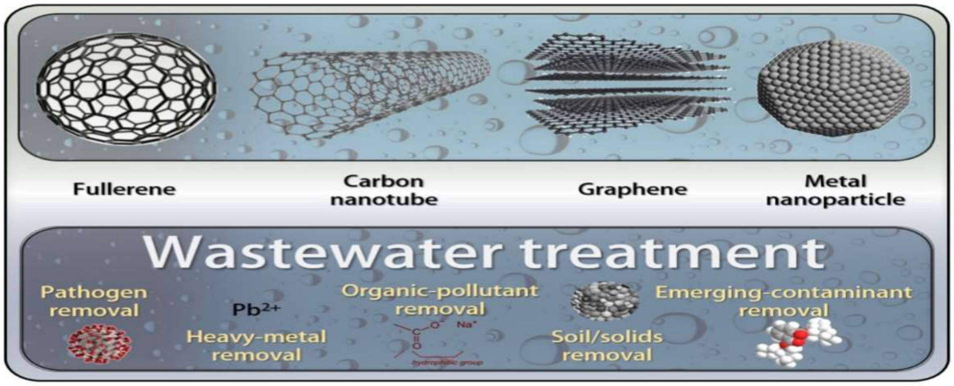

Fig 3: Different types of nanoparticles used for the treatment of water.

CONCLUSION

Different nanoparticles serve diverse functions within industrial and technological applications. Nanoparticles are considered among the safest and most optimal particles engineered for targeted delivery. Through this methodology, numerous engineering components, medical devices, and parts for heavy electrical power systems have been developed. This review aims to facilitate the synthesis and characterization of novel nanoparticles that could be safer and environmentally sustainable.

DECLARATIONS

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Authors' Contribution: Muhammad Shahzaib; Data Curation, Methodology, Wiring Original draft, Muhammad Usman: Conceptualization, Supervision, Editing, Muneeb Ur Rahman: Formal Data Analysis, Writing, Review and Editing, Muhammad Adnan Sami Khan: Data Collection, Writing, Review and Editing, Iqra Yaseen: Writing, Review and Editing

Generative AI Statements: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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