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A REVIEW ON DIFFERENT TYPES OF NANOPARTICLES, CHARACTERIZATION TECHNIQUES AND THEIR ROLE IN PHOTOCATALYTIC REMOVAL OF DYES AND INDUSTRIAL POLLUTANTS

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ABSTRACT:

Water is a necessary component of life, and all living things depend on water to exist. Water pollution is caused by numerous natural and anthropogenic causes. Numerous industries release a significant volume of wastewater into the environment each year. Among all the pollutants, the colours included in effluents are highly mutagenic, carcinogenic, and non-biodegradable, and they seriously affect any nearby living things. There are several techniques employed to treat the wastewater in order to lower the contaminants. There are numerous conventional techniques to remediate contaminants from wastewater, but recently, adsorption technologies have gained much more influence as compared to conventional wastewater treatment processes. It is proved that adsorption techniques are capable of producing water of the desired quality. The main objective of this paper is to give a general overview of the different types of nanoparticles, their synthesis methods, characterization techniques, and their function in the photocatalytic removal of numerous

dangerous water pollutants and dyes.

KEYWORDS: *Wastewaters; Adsorption, Nanoparticles; Dye Decolouration; Photocatalytic Degradation.*

INTRODUCTION:

Water is the most important component of human life. Without water, life would not be possible on earth, and it is a crucial natural resource. More than 70% of the surface of the earth consists of water; of that, 97% is salt water, which is technically unfit for human consumption. The remaining 2% is present in glacier ice, which is located very far from where people live. The remaining 1% is surface water, which we use for many different things, including drinking, washing, irrigation, and industrial purposes ***(Shiklomanov, 1993)***. Water is not a renewable resource, and because of climate change, rapid industrialization, and human activity, the water resources are becoming depleted **(*Bell and Buckley, 2003; McMullan et al., 2001*).** One of the biggest problems the world faces today is water contamination.

Over the years, the only option to get rid of wastewater was to release it into the environment. Due to that, the permissible discharge levels has been greatly surpassed, changing the qualities of the water and contaminating the ecosystem to the point that certain uses of our natural resources are no longer possible. There are two ways to solve these issues: through regular prevention and control measures that limit waste output using various treatment options.

Presently, there are a number of wastewater treatment systems in use, and nanoparticles are an emerging technology for pollutant removal. The adsorption phenomenon has garnered interest in the search for cutting-edge technologies for the remediation and reduction of pollutants. A solid phase (bio sorbent) and a liquid phase (solvent, typically water) contain dissolved species to be sorbed (sorbate, metal ions). Due to sorbent has increased attraction for sorbate species, these latter are drawn to it and adhere to it by various processes. The main advantage in the process of adsorption is the utilisation of non-living biomaterials, which minimises the prerequisite for remarkable care and maintenance as well as acting as an inducer in remediating toxic high levels of contaminants **(*Basso et al., 2002*)**.

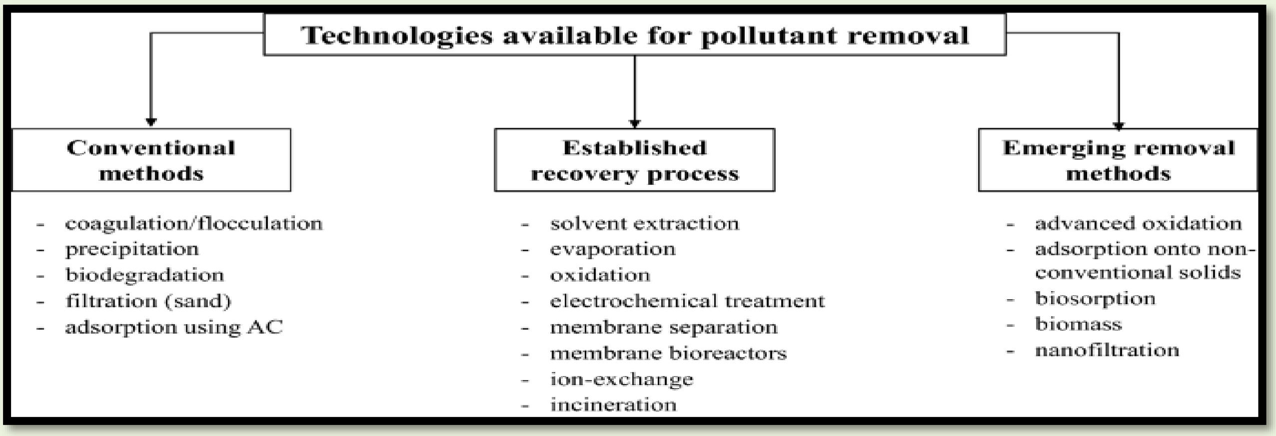

Figure 1 Available Technologies for Pollutant Removal

"Nanotechnology" is defined as the creation, analysis, and utilisation of structures with precise control over their size and shape at the nanoscale. Materials characteristics at the nanoscale might be significantly dissimilar from those at a larger scale. According to several scholars, nanotechnology is anticipated to have a significant impact on society, the economy, and daily life in the future ***(Parr, 2005)***. Nanomaterials have different physicochemical characteristics. Metal oxide nanoparticles stand out among other nanomaterials in terms of their special qualities.

Different metal oxides, sulphides, polymers, core-shells, and composite NPs are prepared using a number of techniques, which are broadly classified into three categories: chemical methods, physical methods, and biological methods.

There are two key approaches for the production of nanoscale materials: top-down nanofabrication starts with a large structure and proceeds to make it smaller through successive cuttings, while bottom-up nanofabrication starts with individual atoms and builds them up to a nanostructure.

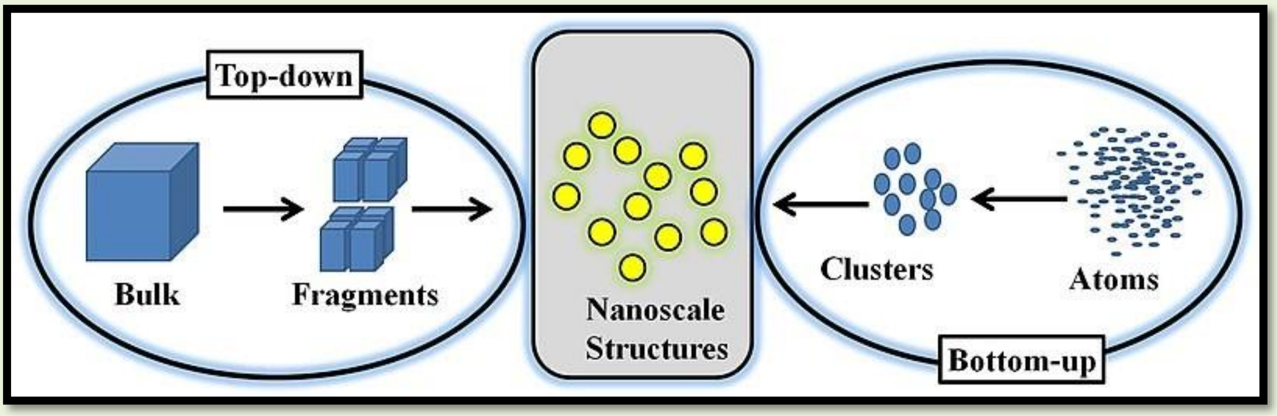

Figure 2 Approaches for production of Nanostructures

Key Characteristics of Nanoparticles

- It is prone to agglomeration and has a high surface area, volume ratio, activity, and catalytic surface.

- Distinct physical characteristics compared to the bulk material.
- Special light scattering characteristics and the surface Plasmon resonance effect, which is essentially required for optical and photocatalytic degradation.
- Novel chemical characteristics include a low number of coordination sites at the surface compared to the bulk of the material, as well as notable effects on catalytic properties, which are further amplified in the case of nanoparticles with hollow or porous cores.

Nanomaterial types and classification

- The majority of modern nanoparticles and nanomaterials can be divided into four material-based categories.
- **Nanomaterials based on carbon:** These nanomaterials often include carbon and have morphologies like hollow spheres, tubes, or ellipses. Carbon nanotubes, fullerenes (C60), graphene (Gr), carbon nanotubes (CNTs), carbon black, and the group of NMs that are carbon-based include carbon anions. With the exception of carbon black, the main production techniques for these carbon-based compounds include laser ablation, arc discharge, and chemical vapour deposition (CVD).
- **Inorganic-based nanoparticles**: metal and metal oxide nanoparticles are among these categories. These NMs can be synthesised into ceramics, metal oxides, semiconductors, such as silicon, and metal NPs, such as Au or Ag.
- Organic-based **nanomaterials:** nanomaterials with a largely organic composition are referred to as organic-based nanomaterials, as opposed to those comprised of carbon or other inorganic substances. Organic nanomaterials can be converted into useful structures such as dendrimers, micelles, liposomes, and polymer nanoparticles by the self-assembly and design of molecules with the help of noncovalent (weak) interactions.
- **Composite-based nanomaterials**: Composite nanomaterials are multiphase NPs and NSMs having one phase on the nanoscale dimension that can be mixed with other NPs, with bulkier materials (for instance, hybrid nanofibers), or with more sophisticated structures, like metalorganic frameworks**.** Any combination of carbon-, metal-, or organic-based NMs and bulk materials made of metal, ceramic, or polymer can be used to create the composites.

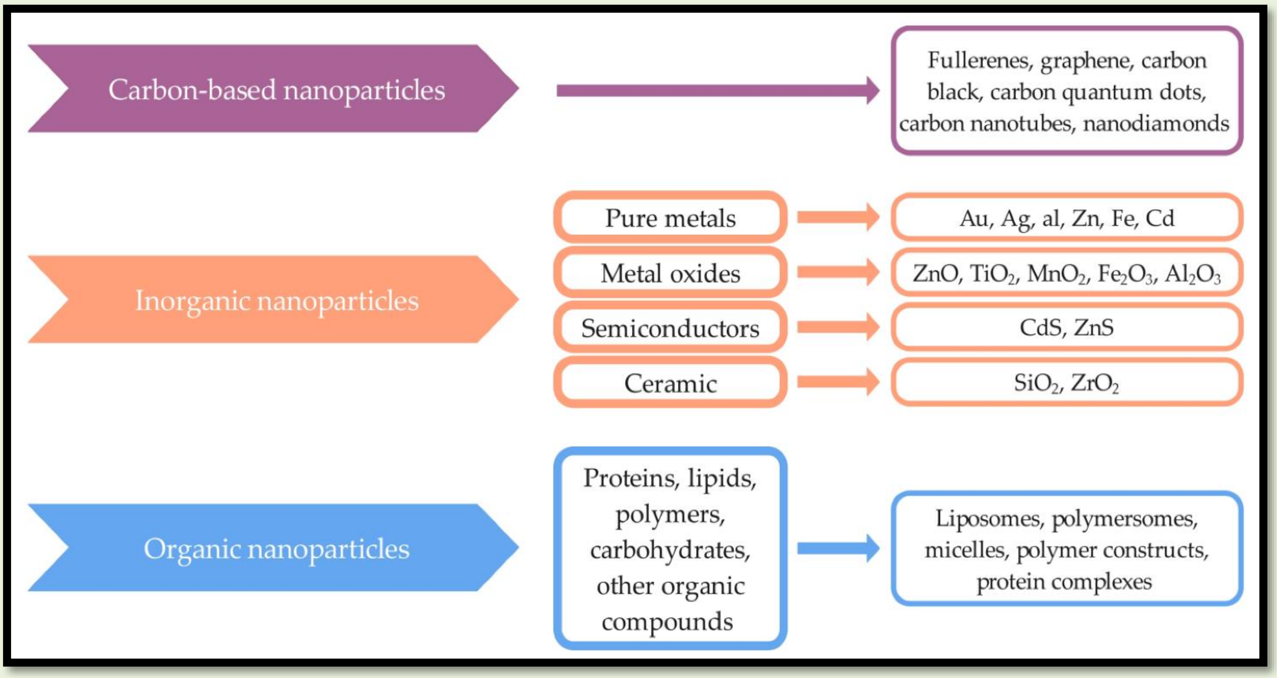

Figure 3 Classification of Nanoparticles

Characterization of Nanoparticles

Understanding the study based on nanoparticles requires knowledge of morphology, crystal structure, and elemental composition. Common techniques used for morphological analysis include transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM), particle size analysis (PSA), dynamic light scattering (DLS), etc.

X-ray Diffraction (XRD)

The XRD spectrum of nanoparticles provides information about structure and crystallinity. The strong intensity and narrow width of diffraction peaks are indications of a high crystallite product. Based on Scherer's equation, the crystallite size of the nanoparticles is estimated from the more intense peak of the XRD spectra. This method, which is employed to determine whether a particle is metallic, provides information on the size, shape, and translational symmetry of the unit cell from peak positions as well as information on the electron density inside the unit cell, namely the locations of the atoms, from peak intensities.

UV-visible spectroscopy:

The optical characteristics of a solution are ascertained via absorbance spectroscopy. The amount of light absorbed is determined after light passes through the sample solution. When the wavelength is changed and absorbance at each wavelength is measured, Beers-Lambert's law can be applied to the absorbance to determine the solution's concentration.

Fourier transform infrared spectroscopy (FTIR)

The FTIR technique offers information about the vibrational state of adsorbed molecules and, therefore, the nature of surface complexes. It also determines the nature of associated functional groups and structural characteristics of biological extracts associated with nanoparticles by plotting the graph of infrared intensity vs. wavelength of light.

Energy Dispersive X-Ray Analysis (EDX)

An x-ray technique called Energy Dispersive X-Ray Analysis (EDX), often known as EDS or EDAX, is used to determine the elemental makeup of materials.

Scanning Electron Microscope (SEM)

The scanning electron microscope is used to determine the dimensions, morphologies, and forms of the produced nanoparticles. SEM provides desired high-resolution images of a sample's surface. The scanning electron microscope operates on the same principles as an optical microscope, but instead of counting photons, it counts electrons that have been dispersed from the material. The wavelength of electrons can be made shorter than that of photons because they can be accelerated by an electric potential. The SEM can now magnify pictures up to a factor of 20,000. It uses a conductive or sputter-coated sample and has a sensitivity of 1 nm to measure particle size. **(Asim Umer et al., 2012).**

Transmission electron microscopy (TEM)

Transmission electron microscopy is a type of microscopy in which an electron beam is passed through an ultra-thin object, reacting with it as it passes. The interaction of the electrons passing through the material results in the formation of an image, which is then magnified and focused onto an imaging device, like a fluorescent screen, on a layer of photographic film, or detected by a sensor like a CCD camera. In a variety of scientific domains, including the physical and biological sciences, TEM is a key analytical technique. TEM is used in the study of semiconductors, nanotechnology, pollution, virology, cancer, and materials science.

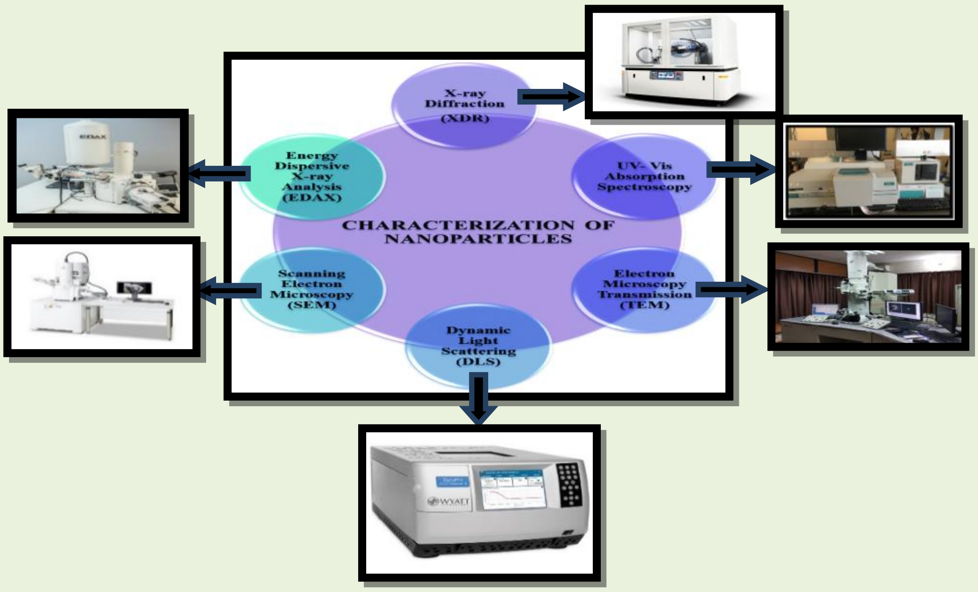

Figure 4 Characterization techniques of Nanoparticles

Metal oxide nanoparticles as photo catalyst

The photocatalytic process has been improved by the development of several catalysts. Metal oxide nanoparticles can be quickly oxidised into hydroxides or oxides and are less hazardous. Another key characteristic is its band gap, which, by detecting energy from the light source, permits both the oxidation and reduction processes. As a powerful photocatalyst, many metal oxide nanoparticles are used. Some of those are TiO2, ZnO, Bi2O3, Fe2O4 ***(Alinezhad et al., 2022)***, WO3, CuO, Cu2O ***(Shete et al., 2022)***, SnO2, CeO2, BiVO4, Bi2WO6, InTaO4, Zn1.7GeN1.8O, ZnAl2O4, and ZnGaNO ***(Ahmad et al., 2022)***. Numerous morphologies exist in these metal oxides, including nanoparticles, nanospheres, nanofibers, nanotubes, nanoribbons, nanosheets, etc. The effectiveness of a photo catalyst is likewise impacted by these morphologies ***(Dessie et al., 2021).***

Metal oxide Nanostructures have been widely used in the field of photo catalysis, out of which nanoparticles are the most commonly exploited due to their larger surface area responsible for the catalytic activity and better chemical stability ***(Linda et al., 2016)***.

Photocatalytic Removal of Dyes

According to Wesenberg ***et al. (2003)***, companies currently produce thousands of different dyes and pigments. The use of synthetic, complex organic colours is growing. Paper, textiles, printing, and dye factories are just a few industries that use synthetic dyestuffs. The bulk of dyes and hazardous metals are used in the colour industry; according to reports, dyes are light-stable and non-biodegradable compounds ***(Baran et al., 2008)***. To reduce the risk of environmental pollution, such rubbish must be treated before being dumped into the environment. For which it is determined that the adsorption technique is the most effective degrading method ***(Kumar et al., 2014)*** because it is straightforward and inexpensive, Dye molecules are adsorbed on the surface of an adsorbent by hydrogen bonds, van der Waals interactions, or hydrophobic forces.

The main criteria influencing how well most adsorption techniques work depend on the concentration of solution, pH, temperature, contact time, adsorbent dosage, adsorbent size, and particle interaction affinity. Nanomaterials, which have a high surface-to-volume ratio, are expected to be the future building blocks of cutting-edge technology in a range of industries because of their exceptional properties (***Lattuada and Hatton 2011)***. Dyes undergo photocatalytic treatment, which converts organic contaminants into harmless by-products like carbon dioxide and water. In addition to natural dyes, most organic and inorganic substances may be broken down in air or water by photocatalytic oxidation, and nanophotocatalysts can decrease dangerous inorganic pollutants in water. According to ***Kumar et al. (2014***, PAHs are by-products of both natural and human processes, including incomplete combustion of solid and liquid fuels, burning of waste, coke ovens, pyrolysis, forest and agricultural fires, and industrial activities.

It has been demonstrated that heterogeneous photo catalysis is an effective method for breaking down organic pollutants in the water and atmosphere. Utilising sunlight in conjunction with a semiconductor photo catalyst expedites the removal of environmental pollutants and the breakdown of extremely hazardous compounds.

Based on the results of photo catalysis, the reactions of dye molecules on photo catalysts can be categorised into the following groups:

(1) Photo decolourization: This simple process uses photo oxidation or photo reduction. (2) Photo degradation: This process produces certain stable chemicals by breaking down dyes. It is most frequently used term for photocatalytic treatment of dyes.

(3) Photomineralization: This is defined as the total breakdown of CO_2, H_2O, N_2, NO_3, and NO_2, among other elements.

Another method of photocatalytic dye degradation can also take place in the presence of visible light due to their ease of absorption of certain wavelengths of light. This process involves the excitation of dye from its ground state (Dye) to its triplet excited state (Dye*) under a visible light photon (λ > 400 nm). An electron is injected into the conduction band, further converting this excited state dye species into a semi-oxidised radial cation or superoxide radical anions, which are created when these trapped electrons react with the dissolved oxygen in the solution, leading to the creation of hydroxyl radicals ($OH^{\cdot}$). The oxidation of organic molecules is mostly caused by these OH radicals.

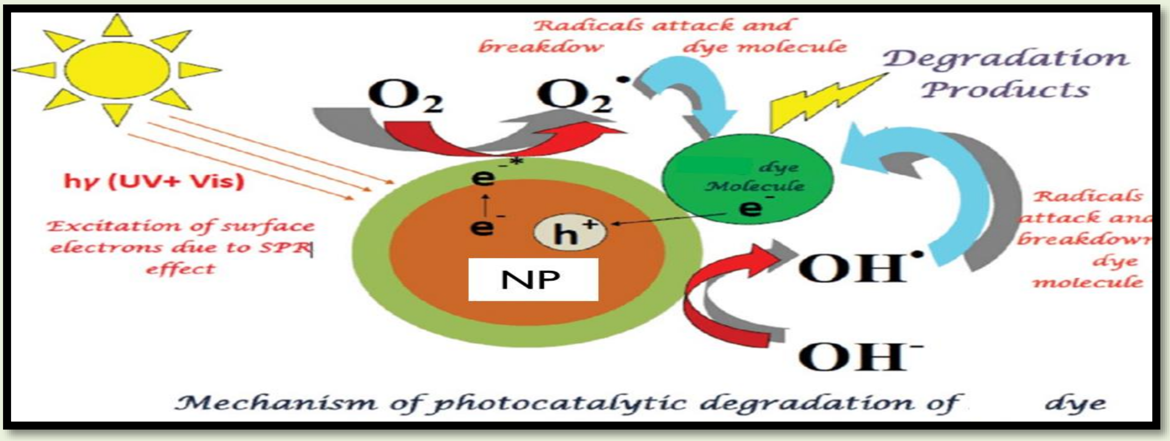

Figure 5 Mechanism of Photocatalytic degradation of dye

CONCLUSION:

Water is essential to all living things since it is the most fundamental element. Adsorptive techniques are the most effective and can be utilized to resolve wastewater issues. Therefore, one of the viable options in this regard for nanomaterial-based wastewater treatment is nanotechnology.

Nanotechny should be utilized as a supplementary technology beside other means for wastewater treatment. Nanotechnology is highly improved the downside of the treatment technologies;

however, it does not eliminated all problems of them. Thus, there is a long way study and comprehend the suitable ways of the combination of diverse treatment systems in order to reach several treatment processes whereby human beings can save the water on Earth for more years to next generations.

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