A review on photocatalytic degradation of organic pollutants

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Abstract

Nanoscience and nanotechnology have changed the world. Materials with dimensions smaller than 100 nanometers are called nanomaterials. The high surface to volume ratio makes the nanomaterials suitable for various application especially photocatalytic degradation. Photo degradation is the process by which a substance is broken down into simpler compounds due to exposure to light, it also involves the chemical break down of pollutants in the presence of light. The present review explores the degradation mechanism of the nano photocatalyst as well as the performance of various nanomaterials on organic contaminants degradation.

Keywords: Nanomaterials, nanotechnology, dyes, organic contaminants, degradation

Introduction

The natural environment can be harmed by the hazardous and uncontrollable organic and inorganic pollutants found in wastewaters from industries such as paper and pulp, chemicals, petrochemicals, dyeing. Scientists are becoming more concerned about environmental safety as a result of the growing usage of organic chemicals in many industrial and agricultural industries. The aquatic environment is severely harmed by organic contaminants (Mouele et al., 2015). Water contamination is mostly caused by industrial effluents, which comprises of toxic organic chemicals (Zhou et al., 2010). Organic pollutants are toxic substances that can cause serious impact to humans when exceeded over a certain limit. Industrial products like plastics, dyes, pesticides organic solvents are the various sources of organic pollutants (Pandey et al., 2023). Chemical pollution poses serious threat to the environment. However, traditional biological and physicochemical treatments suffer from method has a number of drawbacks, such as, hazardous byproducts that need special handling for removal, high temperatures; the requirement for substrate or templates, which makes pre-manufacturing and post-removal challenging etc (Elumalai et al., 2024). Therefore, there is an urgent need to develop effective method to degrade these organic pollutants from waste water. Photodegradation is the process of breaking down substances into simpler compounds owing to the light exposure. In the process the light energy is absorbed by the molecules present in the material causing various chemical reactions like bond breaking, rearrangements etc (Yousif et al., 2013). As wastewater from industries possess variety of inorganic ions, this process also affects the pollutants in presence of light. Residual ions in waste water will have significant effect on the degradation process of organic pollutants (Kim et al., 2009). Therefore, the role of inorganic ions in the dye's degradation process needs to be investigated. Among the different transformation processes, photodegradation is an important factor affecting the fate of organic pollutants in waste water. Therefore, the present review delves into the degradation mechanism of the nano photocatalyst as well as the performance of various nanomaterials on organic contaminants degradation.

Photodegradation Mechanism

Photodegradation is a process where organic contaminants are broken down into simpler, less harmful substances under the influence of light (U.V-Visible) (Xu et al., 2012). This process involves multiple steps:

1. Photon Absorption

Light consists of photons, which contains enough activation energy to break the chemical bonds. On the absorption of the photons by the contaminants, the absorbed energy excites the molecules from their ground state to an excited state. This can be represented as:

$$\mathbf{R+hv \longrightarrow R^{*}}$$

2. MOLECULAR EXCITATION AND BOND CLEAVAGE

In the excited state the contaminant molecules become unstable. This instability may lead to bond cleavage i.e. breaking of chemical bonds within the molecule and oxidation or reduction reactions i.e. interaction with oxygen or other reactive species present in the environment.

3. FORMATION OF THE REACTIVE INTERMEDIATES

Some molecules may generate the reactive intermediates like free radicals or reactive oxygen species, from interaction with oxygen or other environmental factors.

$$\mathbf{R^{*} + O_2 \longrightarrow ROO\cdot}$$

4. DEGRADATION AND TRANSFORMATION

The reactive intermediates undergo chemical reactions, leading to the breakdown of the original contaminants into smaller, less harmful molecules. In some cases, the contaminants are fully mineralized into CO_2, H_2O and inorganic ions:

$$\mathbf{R + O_2 \longrightarrow CO_2 + H_2O + \text{Inorganic byproducts}}$$

Photocatalytic Degradation of organic contaminants

Organic contaminants are a diverse group of chemical compounds primarily derived from human activities like industrial processes, agriculture, pharmaceutical usage, and domestic practices. These contaminants include dyes, pharmaceuticals, pesticides, personal care products, etc., these contaminants are characterized by their complex molecular structures and high stability, making them persistent in the environment. The concern of increase in the accumulation of organic contaminants in the environment has led to the exploration of advanced treatment technologies. Therefore, various studies have been performed for the photodegradation of organic pollutants. Sol gel method was used for the preparation of two titania photocatalysts for the photocatalytic degradation of paracetamol in aqueous solution. The prepared photocatalyst showed better photocatalytic capability in comparison to commercial TiO_2-P25 (Trujillano et al., 2022). Titanium dioxide prepared by the sol-gel method was utilized for the photocatalytic degradation of acetaminophen. The prepared Titanium dioxide showed 99% degradation efficacy at pH 90% at the catalyst dose of 0.15 g of Titanium dioxide (Marizcal-Barba et al., 2022). Zinc oxide nanoparticles prepared via precipitation method using pullulan as biomaterial. The prepared nanoparticles were used for the photocatalytic degradation of paracetamol, amoxicillin with the degradation efficacy of 85.7% and 96.8% (Dayana et al., 2021). Neem leaf extract was utilized for the preparation of zinc oxide nanoparticles for the photocatalytic degradation of sulfadiazine and acetaminophen. Th prepared nano catalyst coated on activated carbon showed 100 % removal of both the pharmaceutical compounds (Sanjeev et al., 2024). Silver nanoparticles as well as silver/magnesium oxide nanocomposite were reared using aloe vera plant extract. The prepared nanoparticles and nanocomposites were used for the degradation of methylene blue, phenol. The prepared nanocomposites displayed 90.18% efficacy f0r dyes degradation and 80.67% for phenol degradation in the time span of 120 mins (Panchal et al., 2022). *Seriphidium oliverianum* leaves extract were used as reducing as well as stabilizing agent for the synthesis of copper oxide nanoparticles. The prepared nanoparticles were used for the degradation of water-soluble industrial dyes. The degradation rate for methyl green was 65% while for methyl orange was 65.07% (Aroob et al., 2023). Silver nanoparticles were also employed for the sunlight induced degradation of Victoria blue dye. The nanoparticles were synthesized using leaf extract of *Solena amplexicaulis* with the efficacy of 99 % at 72 hours of exposure (Joicy et al., 2023). Zinc oxide nanoparticles were synthesized using roots extract of *Ambrosia ambrosiodes* as reducing agent. Photcatalytic studes showed that these nanoparticles degrdaded four dyes i.e. methylene blue, congo red, methyl orange, methyl red with degradation efficacy of 90% within 140 mins (Medina-Acosta et al., 2024). α-Mn_2O_3 nanoparticles were prepared by green sol-gel method using ragacanth gel (TG), as the natural gel. The prepared nanoparticles were found to be spherical in size at 30nm. The photocatalytic performance was evaluated and founded that it degraded Eriochrome Black T at 96% efficacy in 90 min under visible light (Fardood et al., 2024). Rosmarinus officinalis was employed for the preparation of zinc oxide nanoparticles at 80°C and 180°C. The nanoparticles prepared at 80°C degraded methylene blue at 99.65% degradation rate while particles prepared at 180°C showed degradation rate at 98.82% (Algarni et al., 2022). Silver nanoparticles obtained using trisodium citrate were also used for dyes degradation. The prepared nanoparticles degraded orange blue dyes ar the rate of 97.4% rate in 5 mins (Gola et al., 2021).

Conclusion

Recently, the increasing worldwide contamination of natural water systems with thousands of industrial and natural chemicals is one of the key environmental problems that humanity faces. Photo degradation is quite common in plastics, dyes, pesticides, pollutants, etc. as these substances on exposure to sunlight can weaken and starts getting decomposed. Nanocomposites and nanomaterials are superior photocatalyst that could be utilized for the degradation of organic pollutants under visible and ultraviolet light. However, inspite of significant studies, further research is needed to explore the full potential of nanoparticles and nanocomposites in photocatalytic applications.

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