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Role of Nanoparticles in Dye Degradation

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ABSTRACT

The industrial revolution has marked a strong impact on financial upgradation of several countries, and increase in the industrial establishment globally has direct impact on environment because of the release of unwanted product in air and inside the water bodies. The use of dyes has increased tremendously in various industries ranging from food, leather, textile, paper, cosmetic, pharmaceuticals, etc. The problem has emerged due to disposing of the dyes in the open environment, and mostly it is disposed along with the industrial wastes into the water bodies, which becomes harmful for animals, aquatic life and human health. This review highlights the role of the nanoparticles particularly biosynthesized nanoparticles for eliminating the dyes from the industrial wastewater. There are several methods for the synthesis of nanoparticle including physical, chemical and green synthesis of nanoparticles commonly known as biological method. Among all, the biological method is considered as the rapid, easy, eco-friendly and is being performed at mild conditions. The uses of nanoparticles for removal of dyes from water minimize the hazardous impact and thus considered to be the best approach as far as water quality and safety of environment is concerned.

***KEYWORDS:** nanoparticles, dye, degradation, ecofriendly, industries, wastewater, impact, environment*

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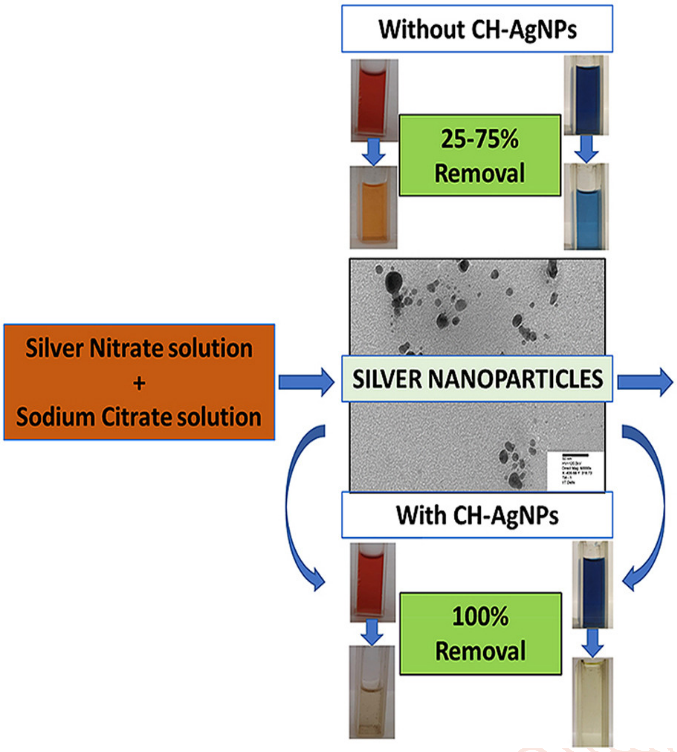
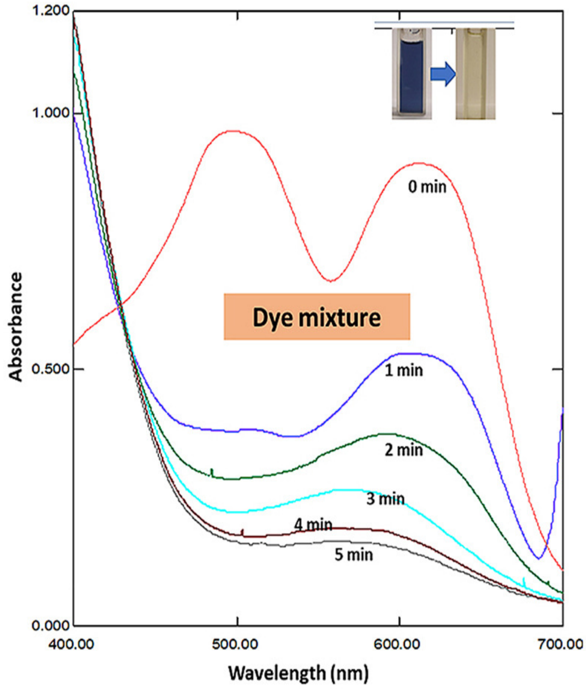
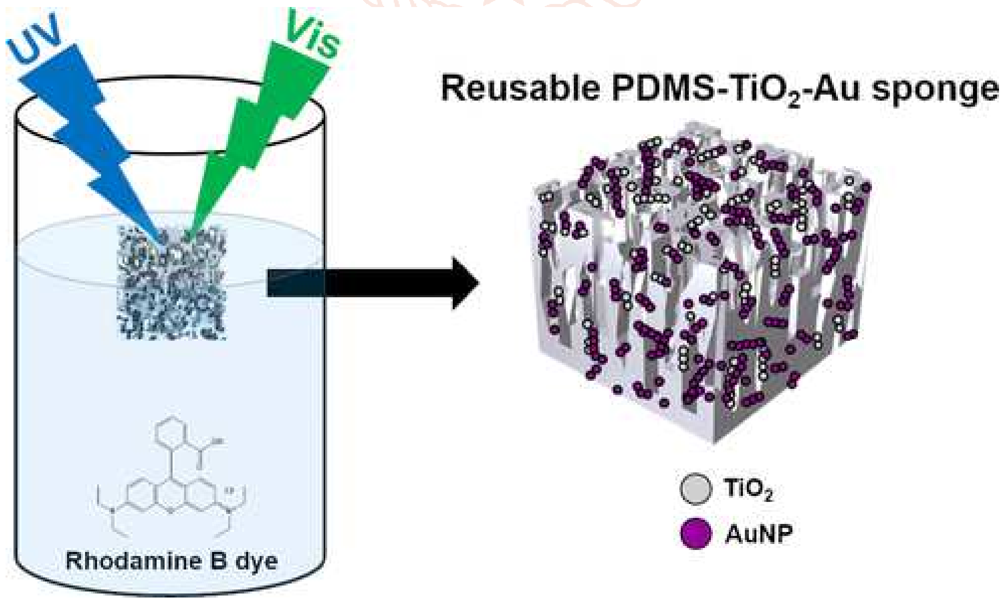
INTRODUCTION

Dye wastewater discharged after improper treatment is very harmful for environment and living creatures. As per mandate, the dye wastewater should be treated well in order to prevent any negative effects after discharge. Although there are various methods which are in use, however most of these methods have some or the other associated disadvantages i.e., high cost, generation of secondary pollutants, low efficiency, complexity etc. [1,2] The was to identify the dye degradation (orange and blue dye-individually/mixture) potential of chemically synthesized silver nanoparticles (CH-AgNPs) along with NaBH4. Literature studies highlighted the efficacy of AgNPs for individual dye degradation, however it is very important to study the degradation potential of nanoparticles in presence of dye mixture (to mimic the natural wastewater condition). In the present study, the rapid synthesis of silver nanoparticles (CH-AgNPs) was obtained by using trisodium citrate solution. The developed CH-AgNPs were examined for UV–vis Spectrophotometry (maxima-422 nm), Zeta Potential (−6.70 mV), and Transmission Electron Microscopy (spherical shape with size range of 8–40 nm), highlighting the nano-size and stability of synthesized CH-AgNPs. For catalytic activity, CH-AgNPs and NaBH4 were tested for dye degradation potential for Orange and Blue dyes individually and in mixture (orange + blue dye). It was observed that with increase in dye concentration from 50 ppm to 200 ppm, NaBH4 showed 28% and 25% removal for blue and orange dyes, respectively. However, when CH-AgNPs + NaBH4 was used, up to 100% degradation was obtained from blue dye, however the degradation of orange dye has shown 97.4% degradation. Further, as the wastewater contains multiple dyes, therefore in dye mixture studies (orange + blue dye- 50 ppm), 100% degradation was achieved with NaBH4+CH-AgNPs in just 5 min, highlighting the efficient catalytic ability of NaBH4+AgNPs. The results clearly highlighted the potential of CH-AgNPs in enhancing the dye degradation of orange and blue dyes-individually and in mixture, therefore the present study is relevant for further research to identify the best dye degradation agents, especially in presence of dyes mixture.[3,4]





A combination of plasmonic nanoparticles (NPs) with semiconductor photocatalysts, called plasmonic photocatalysts, can be a good candidate for highly efficient photocatalysts using broadband solar light because it can greatly enhance overall photocatalytic efficiency by extending the working wavelength range of light from ultraviolet (UV) to visible. In particular, fixation of plasmonic photocatalysts on a floating porous substrate can have additional advantages for their recycling after water treatment. Here, we report on a floating porous plasmonic photocatalyst based on a polydimethylsiloxane (PDMS)–TiO2–gold (Au) composite sponge, in which TiO2 and Au NPs are simultaneously immobilized on the surface of interconnected pores in the PDMS sponge. This can be easily fabricated by a simple sugar-template method with TiO2 NPs and in situ reduction of Au NPs by the PDMS without extra chemicals. Its ability to decompose the organic pollutant rhodamine B in water was tested under UV and visible light, respectively. The results showed highly enhanced photocatalytic activity under both UV and visible light compared to the PDMS–TiO2 sponge and the PDMS–Au sponge. Furthermore, its recyclability was also demonstrated for multiple cycles. The simplicity of fabrication and high photocatalytic performance of our PDMS–TiO2–Au sponge can be promising in environmental applications to treat water pollution.[5,6]



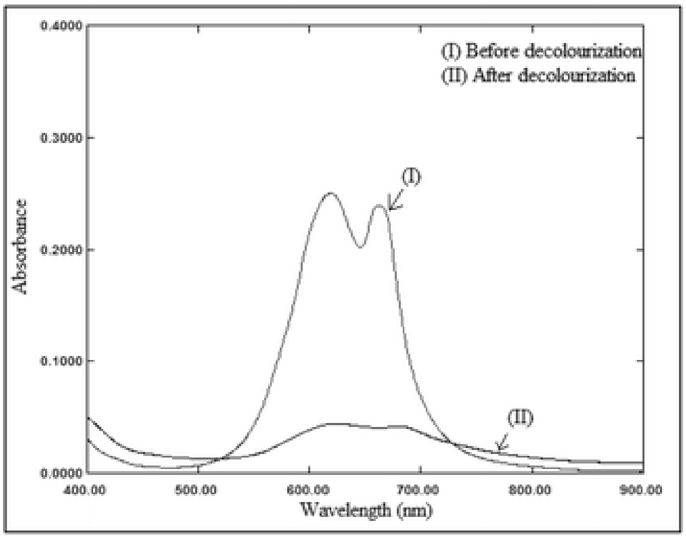
Discussion

Recently, photocatalytic activity by metal nanoparticles sought significant attention due to the fact that it has the characteristic properties of degrading organic compounds under solar light illumination in the case of metal catalysts. Compared to traditional approaches, this process is low cost and does not produce toxic goods.

Nanotechnology allows the development of nanoparticles with regulated size, design, and variance of materials at the nanometer scale length, with the aim of using them to enhance human health. Metal nanoparticles, among all nanoparticles, have a broad variety of applications in areas such as bioimaging, sensor growth, and data processing and novel applications in the biomedical research sector. The late application of metallic silver and silver nanoparticles as antimicrobial operators in various products started, for example, powder and paint, animal feed, covering of the catheter tube, wound patch dressing materials, and water purifying treatments with a negligible danger of toxification in human beings. The green methodology of nanoparticles prepared from natural substances is gaining incredible popularity because it is more environmentally friendly, less harmful, and less time consuming; at present, plant materials are utilized for nanoparticles' formation because they are more perfect than the microorganism-mediated nanoparticles' procedure since they are difficult to handle.[7,8]

Plant extract-based synthesis of nanoparticles is having tremendous success due to its compatibility, environmentally-friendly, and least time consuming properties . In a recent study, silver nanoparticles were effectively fabricated using the Cordia dichotoma (common name: gonda) leaf extract, and the silver and iron nanoparticles synthesized were used in the degradation of dyes. A flowering plant Cordia dichotoma is species from the family of borage, and it is boraginaceous which is native to the regions of western Melanesia, northern Australia, and Indomalayan realm. Common vernacular names include Indian cherry, bird lime tree, pink pearl, glue berry, anonang, cumming cordia, snotty gobbles, fragrant manjack, and lasoda (gunda), respectively. Cordia dichotoma is a deciduous tree with a short bole and a spreading crown that grows to be small to intermediate in height. The stem bark is greyish brown in color and can be smooth or wrinkled over its base.[9,10] The flowers are short stalked, whitish, and open only at night. The fruit is smooth, green-yellow, or pink-yellow globose that becomes black after ripening, and the pulp becomes viscid. Fabricated silver nanoparticles under exposure to sunlight have been exposed to dye degradation operation. Though a lot of work has been done to measure the performance of many adsorbents for dye degradation from industries, yet very little work has been done to model the dye degradation process to evaluate the effect of various parameters on the dye degradation process. This modelling enables the future prediction and indicates the importance of various factors in the real system. The numerical iterative Laplace transform method is employed to simulate the degradation process of dyes from wastewater.

Nickel nanoparticles were synthesized and used to decolourize dye effluent. C. I. Reactive Blue 21 was taken as a reference dye, and polyvinyl pyrrolidone (PVP) was used as a stabilizer to prevent agglomeration of nanoparticles. Characterization of nanoparticles was done by a laser light scattering particle size analyzer, X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM). Various parameters like pH, dye concentration, nanoparticle concentration, alkali addition, salt addition and duration studied for dye decolourization. To confirm the attachment of degraded products of dye on the nanoparticles, FT-IR analysis was done. About 98 % colour removal with simultaneous reduction in chemical oxygen demand (COD) was achieved.[11,12]



UV-visible spectra recorded before and after decolourization of Rhodamine Blue -21 dye by using nickel nanoparticles

The catalytic degradation of methylene blue (MB) was performed using Co NPs. The Co NPs act as efficient catalyst due to large surface to volume ratio. The maximum catalytic degradation of dye is 92.05% which was obtained in very short time. SEM images elaborate that the synthesized Co NPs have aspherical shape with diameter >122 nm.

The synthesized copper nanoparticles (Cu-NPs) were characterized by Zeita sizer and SEM. Cu-NPs were applied to decolorize Reactive Blue 19 dye. Different experimental conditions like concentration of reactive Blue 19 dye, concentration of copper nanoparticles, pH and temperature were optimized. The degrading potential of copper nanoparticles increased their applicability for the decolorization of Reactive Blue 19 dye. Reactive Blue 19 dye was maximum decolorized (90.18%) at aconc. of 0.03%, 4 mg Cu-NPs, pH 10 at 50ºC. The effectiveness of the method was evaluated by water quality assurance parameters such as total organic carbon (TOC) and chemical oxygen demand (COD). The reaction products were characterized by FTIR spectral studies.[13,14]

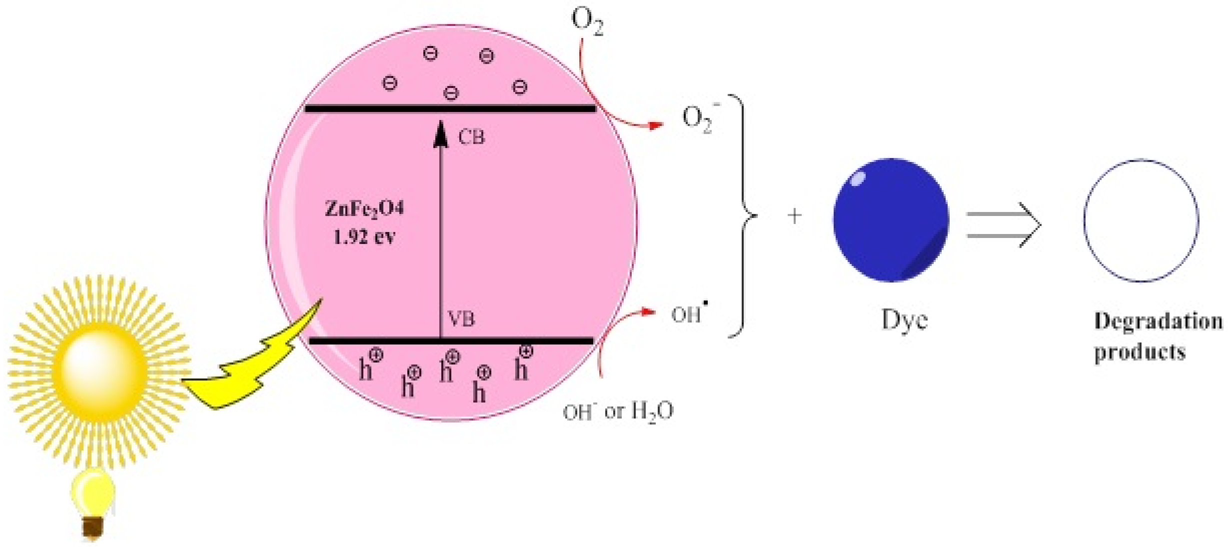
Results

Organic dyes are one of the most commonly discharged pollutants in wastewaters; however, many conventional treatment methods cannot treat them effectively. Over the past few decades, we have witnessed rapid development of nanotechnologies, which offered new opportunities for developing innovative methods to treat dye-contaminated wastewater with low price and high efficiency. The large surface area, modified surface properties, unique electron conduction properties, etc. offer nanomaterials with excellent performances in dye-contaminated wastewater treatment. For examples, the agar-modified monometallic/bimetallic nanoparticles have the maximum methylene blue adsorption capacity of 875.0 mg/g, which are several times higher than conventional adsorbents. Among various nanomaterials, the carbonaceous nanomaterials, nano-sized TiO_2, and graphitic carbon nitride (g-C_3N_4) are considered as the most promising nanomaterials for removing dyes from water phase. However, some challenges, such as high cost and poor separation performance, still limit their engineering application. This article reviewed the recent advances in the nanomaterials used for dye removal via adsorption, photocatalytic degradation, and biological treatment. The modification methods for improving the effectiveness of nanomaterials are highlighted.

Nanotechnology provides an innovative platform that is inexpensive, reasonable, having least chances of secondary contamination, economical, and an effective method to concurrently eradicate numerous impurities from contaminated wastewater. Presently, different researches have been conducted exhibiting versatile multifunctional nanoparticles(NPs)that concurrently confiscate several impurities existing in the water. Nanotechnology helps in eliminating impurities from water through the rapid, low-cost method. Pollutants such as 2,4-dichlorophenol (death-causing contaminant as it quickly gets absorbed via the skin), or industrial dyes including methyl violet (MV) or methyl orange (MO) causing water contamination. Nanotechnology shows a promising and environmental friendly method to resolve the restrictions of current and conventional contaminated water treatment. We can progress the technology, without influencing and affecting the natural earth environment conditions. Dyes are widely used to colour products in textile, leather tanning, cosmetics, pigment and many other industries. Effluents discharged from these industries cause potential hazards to environment and human health. Hence, the removal of dyes from water/wastewater has gained a huge attention in recent years. So far, biological, chemical and physical methods are the traditional techniques, of which adsorption is found to be a more effective and cheap method for removing dyes. Nanotechnology has applied successfully to the water/wastewater treatment and emerged as a fast-developing promising field. Application of nanomaterials (NMs) in dyes removal seems to be an efficient way.[13]

Photocatalytic degradation of commercial textile azo dyes such as Reactive Red 120 (RR 120), Acid Orange 20 (AO 20), Reactive Orange 16 (RO 16) and Congo Red (CR) was studied under UV light and visible light irradiations of wave length 365 nm and 420 nm respectively over bare and modified titania catalysts such as TiO2, 1% Ag/TiO2, 30% TiO2/SiO2 and 1% Ag/30% TiO2/SiO2. On comparison of the catalytic activity of all the synthesized catalysts under UV and Visible irradiations, it was found that the composite catalysts showed higher photocatalytic activity than bare TiO2. Among the catalysts 1% Ag/30% TiO2/SiO2 composite catalyst was the best catalyst for the decolourization of the chosen dyes. Results obtained showed that the time taken for the complete decolourization of dyes was found to be significantly different for different dyes under both UV and visible light irradiations. Among the four dyes, AO 20 decolourised completely (100%) in 2 hrs, whereas Congo Red (CR) decolourised to the least extent (35%) over 1% Ag/30% TiO2/SiO2 under UV light irradiation. Experiments carried out under dark condition in the presence of catalyst revealed very high adsorption of CR (≈60%) over titania catalysts and hence this could be reason for suppressed catalytic activity of 1% Ag/30% TiO2/SiO2. Various optimization studies such as effects of substrate concentration, weight of catalyst and substrate pH were carried out. TOC analysis revealed a very high mineralization of all the dyes.

Organic pollutants are the largest kind of pollutants released into waters and wastewater from the some industry and industrial processes. Photocatalytic degradation is one of the significant and effective methods to remove the dyes and other organic pollutant from water and wastewater. The zinc ferrite nanomaterials are obtained mainly by thermal methods, sol-gel, co-precipitation, and solid-state or hydrothermal route. Zinc Ferrites have good photocatalytic activity, but when exploited as composite photocatalysts, their photocatalytic efficiency were increased. AS a critical magnetic material, the $ZnFe_2O_4$ spinel structure has been proven to be useful in removal dye, $ZnFe_2O_4$ have photocatalytic activity under visible light irradiation. However, it is possible to improve the efficiency of photocatalysis activity of $ZnFe_2O_4$ by coupling it with another semiconductor or coupling it with carbon nanotubes and graphene, resulting in enhanced photocatalytic performance.[14]



Conclusion

Pollutant removal from industrial effluents is a big challenge for industries. These pollutants pose a great risk to the environment. Nanotechnology can reduce the expenditure made by industries to mitigate these pollutants through the production of metallic nanoparticles. Nanoparticles are gaining attention due to their enhanced physical, chemical, and mechanical properties. Using microorganisms in the production of nanoparticles provides an even greater boost to green biotechnology as an emerging field of nanotechnology for sustainable production and cost reduction. Nanotechnology has generated interest among researchers due to its beneficial effects, such as its large provided surface area, the capability of multiple uses, its stability at harsh conditions, easy and efficient manipulations in materials, increased interaction, and many more. [15]

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