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Bio-derived metal and metal oxide incorporated biopolymer nanocomposites for dye degradation applications: A review

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ABSTRACT

Water is an essential requirement for both domestic and industrial purposes. The depletion of accessible resources and an upsurge in the water pollution affect both. One of the main causes of water pollution is industrial discharges, specifically the effluents that emanate from textile factories. From these factories, toxic pollutants are often discharged without any monitoring of pollutant control or eradication. The use of the photodegradation technique has successfully demonstrated the efficient decomposition of these toxic pollutants. Different sizes and shapes of materials have already been explored as photocatalysts. Among them, nanometric photocatalysts turned out to be the most effective. To achieve further advances, biopolymers are introduced alongside nanostructured materials for better recycling, biodegradable, and as an eco-friendly approach. This review aims to explore into metal-biopolymer and metal oxide-biopolymer composites from synthesis to application perspectives. We have also elaborated particularly on studies that explore the composition of metals and metal oxides with biopolymers for the application of dye degradation.

Keywords: *Bio-derived metal and metal oxide; biopolymer; nanocomposites; dye degradation; environmental applications*

1. INTRODUCTION

Water is one of the most essential requirements of our daily lives. But water pollution is constantly restricting available consumable sources of water which is creating havoc chaos around the globe. Consumption of water containing hazardous pollutants is equally harmful to humans as well as for animals. Untreated or partially treated water can pose severe health-oriented threats to all living organisms. Edible food staff is also impacted by contaminated water. Ejected contaminates from textile factories are considered as one of the potential threats which can pollute different water sources as the emitted contaminants are mostly emitted in water bodies. These emanations are mainly comprised of synthetic azo dyes which are non-biodegradable, carcinogenic, and recalcitrant by nature (Singh et al., 2015). So, treating them is a crucial concern to stop their further spreading in different water sources and to achieve that various membrane technologies, adsorbents, and photocatalyst materials are already been developed and their advancements are ongoing (Crini and Lichtfouse, 2019; Dutta et al., 2020). Mostly process such as electrochemical oxidation, photocatalysis, ozonation, ion exchange, filtration, and osmosis are considered as the effective ones to eliminate dye contaminates from water solutions (Singh et al., 2015; Lade et al., 2015).

Photoactivated degradation is a significant technique to eradicate pollutants from water. This process involves the utilization of photocatalysts and light sources. Generation of charge pairs by exposing photocatalyst material to light helps to decontaminate the water solutions *via* oxidation and reduction reactions. The material bandgap is an important factor to determine the working ability of the photocatalysts as photocatalytic degradation involves the transition of electrons between conduction and valence bands. In recent trends use of heterogeneous photocatalysts became an attractive choice for performing dye degradation activity in aqueous or watery solutions. Various oxide materials such as ZnO, CaO, TiO_2, *etc.*, and their composites are already been explored as promising photocatalyst materials which have exhibited outstanding dye decomposing capability (Fujishima and Honda,1972; Mclaren et al., 2009; Xu et al., 2019; Jaiswal et al., 2021a, 2021b). By coupling or surface modification *via* doping also resulted in enhanced photocatalytic performance (Gnanasekaran et al., 2017; Sulaiman et al., 2018). The addition of natural polymers such as cellulose, starch to metal or metal oxide photocatalysts have also shown some positive outcomes. Already studies have depicted that natural polymer individually offers efficient adsorption of pollutants (Anastopoulos et al., 2017). For example, chitosan is been utilized for biosorption of toxic dye (Crini et al., 2019). So to further up-gradation of photodegradation activity researchers have utilized the composites by combining metal or metal oxide with biopolymer (Oliveira et al., 2020; Jaiswal et al., 2018; Haldorai and Shim, 2013). However, it can use to be mentioned that several microalgae have been applied to remove the toxic heavy metals and other pollutants from the contaminated wastewater, also it has been reported for dye removal (Fatima et al., 2020a, 2020b; Jaiswal and Prasath, 2016). Moreover, in few studies photocatalyst materials are synthesized using natural polymers (Sriramulu and Sumathi, 2017; Rabeea et al., 2020). In this review, we are going to elaborate on recent studies on different biopolymer-supported photocatalysts and their workability in degrading dye effluents.

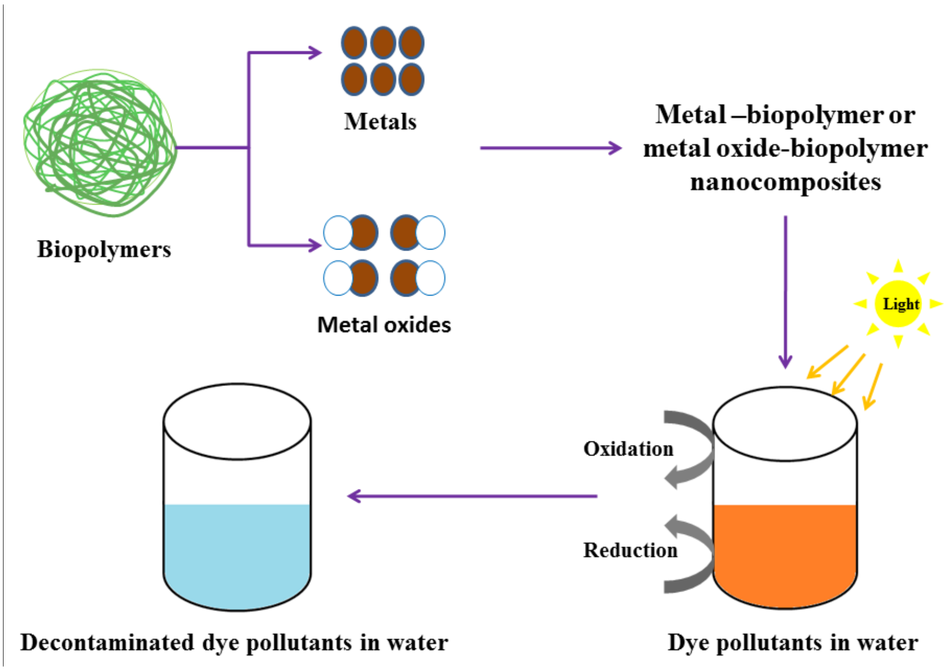

Figure 1. Schematic representation of dye degradation applications of metal and metal oxide-incorporated biopolymer nanocomposites

2. BIO-SYNTHESIS OF METAL AND METAL OXIDE NANOPARTICLES

Frequently used biopolymers for nanomaterials or composite synthesis are cellulose, chitosan, dextran, and starch (Banerjee and Bandopadhyay, 2016; Farshchi et al., 2019; Kolangare et al., 2019). In sources like bacteria, fungi, algae, and plants, these biopolymers can be found. Ex-situ and in situ techniques are mostly used in synthesizing metal/polymer nanocomposites. Ex-situ involves individual preparation of polymer and metal nanoparticles and afterward combining them *via* employing solution blending method or melt compounding method. On the other hand in situ technique comprises a dispersion of metal nanoparticles in monomeric solution and polymerizing them later on (Tamayo et al., 2019). Another way of in situ preparation is metal ion reduction and thereafter polymerization. To synthesize metal oxide nanoparticles methods such as thermal evaporation, pulsed laser deposition, sputtering deposition, molecular beam epitaxy, sol-gel, solvothermal etc are used. And to prepare further metal oxide/biopolymer composite methods such as in-situ polymerization, sol-gel approach and direct blending/mixing are utilized (Prasanna et al., 2019). Among these techniques, sol-gel has fewer advantages over other techniques which are high purity, less sintering temperature, and uniform distribution of particles. However, all three processes are quite frequently employed for preparation. In preparation of these composites, few reaction parameters such as temperature, type and amount of solvent, etc are precisely monitored as these impact the morphology of the composite. Apart from conventional techniques, the green synthesis approach are also been mentioned by researchers to avoid the usage of toxic chemical compounds for synthesis purposes (Edison and Sethuraman, 2012).

3. METAL AND METAL OXIDE-INCORPORATED BIOPOLYMER NANOCOMPOSITES

Owing to suitable surface chemistry, pore size, and mechanical properties, metal-incorporated nanostructured materials have exhibited excellent photo-degradation of harmful dyes (Opoku et al., 2017). Incorporating metal into different types of polymeric nanomaterials has elevated transfer of generated charges and hence metal oxidation has been reduced

(Subramanian et al., 2001). By this method electron lifetime as well as reactivity has been increased. Polymeric materials like resin, with metal incorporation, have already been commercially utilized as a reaction catalyst (Kralik and Biffis, 2001). Grafting metal nanomaterials on various polymeric substances can potentially improve stability and compactness (Tamayo et al., 2019). Moreover, the resultant metal incorporated polymeric materials offer better homogeneous size distribution compared to the individual metal nanoparticles. As a result, much stable performance can be achieved. For the first time, Rabeea et al., (2020) used the Enoki mushroom fruit-body extract to prepare extracellular mycosynthesized triangular and spherical gold nanoparticles (Rabeea et al., 2020). The as-synthesized nanoparticles were employed to decompose methylene blue dye. Tamayo and his group mentioned in their studies that gold nanostructured particles have excellent capability of decomposing harmful organic dyes because of having wide substrate specificity (Tamayo et al., 2019). Previously, extracts of the different plants and parts of the plants such as *Pleurotus sajor caju*, *Solanum tuberosum*, *Pleurotus ostreatus*, *T. chebula*, *Agaricus bisporus*, and *Ganoderma lucidum* were used to synthesize different nanostructured materials including silver nanoparticles for investigating the degradation of various dyes and several other applications (Sriramulu and Sumathi, 2017; Edison and Sethuraman, 2012; Nithya and Ragunathan, 2011; Roy et al., 2015; Verma et al., 2021; Ahmad et al., 2020, 2021a, 2021b). Apart from gold and silver, lanthanum was also employed because of its ability to interact with biopolymer-containing functional groups to construct complexes with superior surface area. Sirajudheen and Meenakshi, (2019) have examined the chitosan/lanthanum (La^{3+})/graphite composite to study the decontamination of the methylene blue dye solution (Sirajudheen and Meenakshi, 2019). Similarly, Kusrini et al., (2018) also studied the adsorption impact of lanthanum/chitosan/modified graphite waste composite on various dyes such as methylene blue, rhodamine B, methyl violet, and methyl orange (Kusrini et al., 2018). The author particularly mentioned that a higher concentration of lanthanum (0.03 M) resulted in higher adsorption. The graphene and graphene-based composites have been reported to be easily synthesized using different green route approaches including microwave irradiation for numerous applications (Jaiswal et al., 2018; Sudhakar et al., 2017, 2018).

Besides incorporating metals, incorporating metal oxide with biopolymers has also been proven as an efficient photocatalyst. The combination of biopolymers and metal oxide enhanced physicochemical properties of the resultant nanomaterials which further led to the better decomposing complex chemical structure of toxic dyes and hence superior photocatalytic performance has been achieved (Prasanna et al., 2019). The schematic representation of dye degradation applications of metal and metal oxide‑incorporated biopolymer nanocomposites has been shown in Figure 1. ZnO is known for its excellent ability as an efficacious catalyst (Dutta et al., 2019). As a photocatalyst also it has exhibited some noticeable outcomes (Ravishankar et al., 2014). Farzana and Meenakshi, (2015) have examined the degradation efficiency of ZnO incorporated chitosan beads using Reactive Red 2 dyes (Farzana and Meenakshi, 2015). The author investigated both the individual ZnO and ZnO/chitosan beads under both UV and visible light irradiation. The observation which is needed to be mentioned is that the ZnO under UV radiation and ZnO/chitosan beads under visible light exhibited superior performances. However, the overall highest degradation efficiency of Reactive Red 2 dye was achieved using ZnO catalyst under UV irradiation. Similarly, Haldorai and Shim, (2013) synthesized chitosan encapsulated ZnO to investigate the degradation performance of methylene blue dye (Haldorai and Shim, 2013). Here, the author recycled the ZnO/chitosan hybrid catalyst 5 times to study the impact on the photocatalytic performance of the dye but no specific change was observed. In another study, Khan et al., (2019) investigated the degradation impact of CuAg/ZnO/carbon black/cellulose acetate hybrid nanocomposite on various harmful dyes such as methylene blue, methyl orange, rhodamine B, and congo red out of which congo red have shown the fastest decomposing rate (Khan et al., 2019). Recently Kumar et al., (2021) reported the synthesis of ZnO/SnO_x photocatalyst and its utilization in the degradation of Methylene blue (Kumar et al., 2021). The author illustrated that tin oxide (SnO_x) as a coating substance helps to enhance the chemical stability and photo-activity of the composite. The main aim of the study was to prepare ZnO/SnO_x incorporated in a chitosan matrix, however, the author only employed ZnO/SnO_x composite to study the degradation and ZnO/SnO_x/chitosan nanocomposites to study antifouling application. The author further added that ZnO/SnO_x/chitosan nanocomposites are expected to be exhibiting lesser degradation efficiency compared to ZnO/SnO_x composite due to the loss of surface area (Kumar et al., 2021).

Apart from ZnO/biopolymer composites, TiO_2 incorporated biopolymer has also indicated workable dye degradation outcomes. Dassanayake et al., (2018) reported the synthesis of aerochitin/TiO_2 and its utilization in the degradation of methylene blue dye (Dassanayake et al., 2018). Aerochitin is an excellent sorbent and that is why incorporating TiO_2 in it resulted in better photocatalytic activity. TiO_2/chitosan composites are also explored by researchers. Combining chitosan with TiO_2 has resulted in higher catalytic activity and easy recovery. Farzana and Meenakshi, (2014) prepared TiO_2/chitosan composite to study the degradation of three different dyes (rhodamine B, methylene blue, and reactive red 2). Under UV radiation, reactive red 2 was observed to be almost achieved complete degradation compared to the other two dyes (Farzana and Meenakshi, 2014). To achieve further improvement in surface properties, Bahal et al., (2019) synthesized TiO_2/chitosan/acrylic acid and employed it to decompose malachite green dye under visible light irradiation (Bahal et al. 2019). The addition of chitosan provided a strong polymeric backbone which helped the functional groups to degrade the dye efficiently. Other than aerochitin and chitosan, TiO_2/cellulose composites were also recommended by researchers to enhance photodegradation ability (Virkutyte et al., 2012; Han et al., 2017; Uddin et al., 2007; Luo and Huang, 2014; Liu et al., 2010; Khaoulani et al., 2015). For an instance, Han et al., (2017) prepared TiO_2/hydroxyethyl cellulose/carboxymethyl hydrogel to examine the degradation of methylene blue dye (Han et al., 2017). The as-synthesized composite not only improved the contact area but also enhanced the interaction probability between the catalyst and the dye. Apart from enhanced photocatalytic performance, the composite also exhibited regenerative capability and self-cleaning properties. Besides ZnO and TiO_2, other metal oxides such as manganese dioxide, iron oxide, and silver oxide incorporated bio-composites were also explored for water decontamination application but still requires further investigation with an extensive approach (Prasanna et al., 2019; Ngah et al., 2011; Adnan et al., 2020; Oliveira et al., 2020; Jusoh et al., 2017). Hence the addition of biopolymers into metal or metal oxide facilitated degradation of pollutants as well as offers recyclability and an environmentally safe approach.

Table 1. Metal and metal oxide−incorporated biopolymer nanocomposites for dye degradation applications.

Catalysts	Light irradiation	Concentration (mg/L)	Type of dye	Efficiency (%)	Time (min)	References
Bio-Ag nanoparticles	UV	10	direct blue 71	98	150	Sriramulu and Sumathi, 2017
Bio-Au nanoparticles	--	5	methylene blue	75	240	Rabeea et al., 2020
MnO_2/cellulose	fluorescent	22	indigo carmine	90	25	Oliveira et al., 2020
Chitosan/lanthanide/graphite	UV	30	methylene blue	94	40	Sirajudheen and Meenakshi, 2019
Chitosan/PANI/Co_3O_4	UV	10	methylene blue	88	180	Shahabuddin et al., 2015
AgO/chitosan	UV	35	methylene blue	72	180	Jusoh et al., 2017
Chitosan/ZnO	UV	30	methylene blue	64	180	Haldorai and Shim, 2013
Chitosan/lanthanum/graphite	UV	100	methyl violet	85	---	Kusrini et al., 2018
Chitosan/ZnO–SnO_x/GA	visible	10^{-3}	methylene blue	98	480	Kumar et al., 2021
CuAg/ZnO/carbonblack/cellulose acetate	UV/visible	5×10^3	congo red	100	~20	Khan et al., 2019
CuAg/ZnO/carbonblack/cellulose acetate	UV/visible	5×10^3	methylene blue	100	~12	Khan et al., 2019
CuAg/ZnO/carbonblack/cellulose acetate	UV/visible	5×10^3	rhodamine B	97	~14	Khan et al., 2019
CuAg/ZnO/carbonblack/cellulose acetate	UV/visible	5×10^3	methyl orange	100	~12	Khan et al., 2019
Chitosan/polyacrylic acid/ TiO_2	visible	100	methylene blue	92	240	Bahal et al., 2019
TiO_2/microcrystalline cellulose	visible	3×10^3	methylene blue	90	240	Virkutyte et al., 2012
Hydroxyethyl cellulose/TiO_2/carboxymethyl cellulose	UV	100	methylene blue	82	30	Han et al., 2017
Aerochitin/TiO_2	UV	10	methylene blue	98	200	Dassanayake et al., 2018

4. CONCLUSIONS

Degradation of carcinogenic dyes by utilizing photocatalysts is a suitable and precise technique. Here in this review, we have illustrated specifically metal and metal oxide incorporated biopolymers and their work efficiency in degrading the dyes. In actual biopolymers such as chitosan, cellulose, etc., offers a strong backbone to the metal/biopolymer of metal oxide/biopolymer hybrid composites, due to which functional groups can easily facilitate the decomposition of the pollutants. In previous sections, we have explained the frequently used synthesis route and application of various biopolymers composite with metal and metal oxides. Also, details have been explained about the impact of combining biopolymers to metal and metal oxides on the degradation efficiency compared to their counterparts. In addition to improved photocatalytic activity, the described composite also provided easy recovery and recyclability of the catalysts which endorses commercial usage of these photocatalysts. Commercial usage of these photocatalysts will not only help to treat the dye effluent discharge from the textile industry but also help to clean up other types of harmful pollutants (arsenic, chromium, *etc.*) usually present in closed water bodies. In this way, we can eliminate threats from water bodies as well as from the environment and be able to move to a safer future.

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DECLARATION

The authors declare no conflict of interest.

5. REFERENCES

Adnan, M. A. M., PHOON, B. L., & Julkapli, N. M. (2020). Mitigation of pollutants by chitosan/metallic oxide photocatalyst: a review. Journal of Cleaner Production, 261, 121190.

Ahmad, W., Jaiswal, K. K., & Soni, S. (2020). Green synthesis of titanium dioxide (TiO_2) nanoparticles by using *Mentha arvensis* leaves extract and its antimicrobial properties. Inorganic and Nano-Metal Chemistry, 50(10), 1032-1038.

Ahmad, W., Kumar Jaiswal, K., & Amjad, M. (2021a). *Euphorbia herita* leaf extract as a reducing agent in a facile green synthesis of iron oxide nanoparticles and antimicrobial activity evaluation. Inorganic and Nano-Metal Chemistry, 51(9), 1147-1154.

Ahmad, W., Singh, A., Jaiswal, K. K., & Gupta, P. (2021b). Green Synthesis of Photocatalytic TiO_2 Nanoparticles for Potential Application in Photochemical Degradation of Ornidazole. Journal of Inorganic and Organometallic Polymers and Materials, 31(2), 614-623.

Anastopoulos, I., Bhatnagar, A., Bikiaris, D. N., & Kyzas, G. Z. (2017). Chitin adsorbents for toxic metals: a review. International Journal of Molecular Sciences, 18(1), 114.

Bahal, M., Kaur, N., Sharotri, N., & Sud, D. (2019). Investigations on amphoteric chitosan/TiO_2 bionanocomposites for application in visible light induced photocatalytic degradation. Advances in Polymer Technology, 2019.

Banerjee, A., & Bandopadhyay, R. (2016). Use of dextran nanoparticle: A paradigm shift in bacterial exopolysaccharide based biomedical applications. International journal of biological macromolecules, 87, 295-301.

Crini, G., & Lichtfouse, E. (2019). Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters, 17(1), 145-155.

Crini, G., Torri, G., Lichtfouse, E., Kyzas, G. Z., Wilson, L. D., & Morin-Crini, N. (2019). Dye removal by biosorption using cross-linked chitosan-based hydrogels. Environmental Chemistry Letters, 17(4), 1645-1666.

Dassanayake, R. S., Rajakaruna, E., & Abidi, N. (2018). Preparation of aerochitin-TiO_2 composite for efficient photocatalytic degradation of methylene blue. Journal of Applied Polymer Science, 135(8), 45908.

Dutta, S., Banerjee, I., & Jaiswal, K. K. (2020). Graphene and graphene-based nanomaterials for biological and environmental applications for sustainability. Octa Journal of Biosciences, 8(2), 106-112.

Dutta, S., Jaiswal, K. K., Verma, R., Basavaraju, D. M., & Ramaswamy, A. P. (2019). Green synthesis of zinc oxide catalyst under microwave irradiation using banana (*Musa* spp.) corm (rhizome) extract for biodiesel synthesis from fish waste lipid. Biocatalysis and Agricultural Biotechnology, 22, 101390.

Edison, T. J. I., & Sethuraman, M. G. (2012). Instant green synthesis of silver nanoparticles using *Terminalia chebula* fruit extract and evaluation of their catalytic activity on reduction of methylene blue. Process Biochemistry, 47(9), 1351-1357.

Farshchi, E., Pirsa, S., Roufegarinejad, L., Alizadeh, M., & Rezazad, M. (2019). Photocatalytic/biodegradable film based on carboxymethyl cellulose, modified by gelatin and TiO_2-Ag nanoparticles. Carbohydrate polymers, 216, 189-196.

Farzana, M. H., & Meenakshi, S. (2014). Synergistic effect of chitosan and titanium dioxide on the removal of toxic dyes by the photodegradation technique. Industrial & Engineering Chemistry Research, 53(1), 55-63.

Farzana, M. H., & Meenakshi, S. (2015). Exploitation of zinc oxide impregnated chitosan beads for the photocatalytic decolorization of an azo dye. International journal of biological macromolecules, 72, 900-910.

Fatima, N., Kumar, V., Jaiswal, K. K., Vlaskin, M. S., Gururani, P., & Kumar, S. (2020a). Toxicity of cadmium (Cd) on microalgal growth,(IC50 value) and its exertions in biofuel production. Biointerface Research in Applied Chemistry, 10(4), 5828-5833.

Fatima, N., Kumar, V., Rawat, B. S., & Jaiswal, K. K. (2020b). Enhancing algal biomass production and nutrients removal from municipal wastewater via a novel mini photocavity bioreactor. Biointerface Research in Applied Chemistry, 10(1), 4714-4720.

Fujishima, A., & Honda, K. (1972). Electrochemical photolysis of water at a semiconductor electrode. nature, 238(5358), 37-38.

Gnanasekaran, L., Hemamalini, R., Saravanan, R., Ravichandran, K., Gracia, F., Agarwal, S., & Gupta, V. K. (2017). Synthesis and characterization of metal oxides (CeO_2, CuO, NiO, Mn_3O_4, SnO_2 and ZnO) nanoparticles as photo catalysts for degradation of textile dyes. Journal of Photochemistry and Photobiology B: Biology, 173, 43-49.

Haldorai, Y., & Shim, J. J. (2013). Chitosan-zinc oxide hybrid composite for enhanced dye degradation and antibacterial activity. Composite Interfaces, 20(5), 365-377.

Han, S., Wang, T., & Li, B. (2017). Preparation of a hydroxyethyl–titanium dioxide–carboxymethyl cellulose hydrogel cage and its effect on the removal of methylene blue. Journal of Applied Polymer Science, 134(23).

Jaiswal, K. K., & Prasath, A. R. (2016). Integrated growth potential of *Chlorella pyrenoidosa* using hostel mess wastewater and its biochemical analysis. International Journal of Environmental Sciences, 6(5), 592-599.

Jaiswal, K. K., Dutta, S., Pohrmen, C. B., Banerjee, I., Das, H. T., Jha, N., ... & Ahmad, W. (2021a). Bio-fabrication of selenium nanoparticles/micro-rods using cabbage leaves extract for photocatalytic dye degradation under natural sunlight irradiation. International Journal of Environmental Analytical Chemistry, 1-18. https://doi.org/10.1080/03067319.2021.1958799

Jaiswal, K. K., Dutta, S., Pohrmen, C. B., Verma, R., Kumar, A., & Ramaswamy, A. P. (2021b). Bio-waste chicken eggshell-derived calcium oxide for photocatalytic application in methylene blue dye degradation under natural sunlight irradiation. Inorganic and Nano-Metal Chemistry, 51(7), 995-1004.

Jaiswal, K. K., Manikandan, D., Murugan, R., & Ramaswamy, A. P. (2018). Microwave-assisted rapid synthesis of Fe_3O_4/poly (styrene-divinylbenzene-acrylic acid) polymeric magnetic composites and investigation of their structural and magnetic properties. European Polymer Journal, 98, 177-190.

Jaiswal, K. K., Sudhakar, S., & Ramaswamy, A. P. (2018). 'Graphene' - World's Thinnest Material for Revolutionizing Applications. Everyman's Sci., 53, 219-223.

Jusoh, R., Setiabudi, H.D., Kamarudin, N.S., & Sukor, N.F. (2017). Chitosan-functionalized Ag nanoparticles for degradation of methylene blue: effect of chitosan pre-treatment. The International Journal Of Science & Technoledge. 5(12), 103-109.

Khan, S. A., Khan, S. B., Farooq, A., & Asiri, A. M. (2019). A facile synthesis of CuAg nanoparticles on highly porous ZnO/carbon black-cellulose acetate sheets for nitroarene and azo dyes reduction/degradation. International journal of biological macromolecules, 130, 288-299.

Khaoulani, S., Chaker, H., Cadet, C., Bychkov, E., Cherif, L., Bengueddach, A., & Fourmentin, S. (2015). Wastewater treatment by cyclodextrin polymers and noble metal/mesoporous TiO_2 photocatalysts. Comptes Rendus Chimie, 18(1), 23-31.

Kolangare, I. M., Isloor, A. M., Karim, Z. A., Kulal, A., Ismail, A. F., & Asiri, A. M. (2019). Antibiofouling hollow-fiber membranes for dye rejection by embedding chitosan and silver-loaded chitosan nanoparticles. Environmental Chemistry Letters, 17(1), 581-587.

Kralik, M., & Biffis, A. (2001). Catalysis by metal nanoparticles supported on functional organic polymers. Journal of Molecular Catalysis A: Chemical, 177(1), 113-138.

Kumar, S., Ye, F., Mazinani, B., Dobretsov, S., & Dutta, J. (2021). Chitosan Nanocomposite Coatings Containing Chemically Resistant ZnO–SnO_x Core–shell Nanoparticles for Photocatalytic Antifouling. International journal of molecular sciences, 22(9), 4513.

Kusrini, E., Wicaksono, B., Yulizar, Y., Prasetyanto, E. A., & Gunawan, C. (2018, March). Textile Dye Removal from Aqueous Solution using Modified Graphite Waste/Lanthanum/Chitosan Composite. In IOP Conference Series: Materials Science and Engineering (Vol. 316, No. 1, p. 012029). IOP Publishing.

Lade, H., Kadam, A., Paul, D., & Govindwar, S. (2015). Biodegradation and detoxification of textile azo dyes by bacterial consortium under sequential microaerophilic/aerobic processes. EXCLI journal, 14, 158.

Liu, X., Gu, Y., & Huang, J. (2010). Hierarchical, Titania-Coated, Carbon Nanofibrous Material Derived from a Natural Cellulosic Substance. Chemistry–A European Journal, 16(26), 7730-7740.

Luo, Y., & Huang, J. (2015). Hierarchical-Structured Anatase-Titania/Cellulose Composite Sheet with High Photocatalytic Performance and Antibacterial Activity. Chemistry–A European Journal, 21(6), 2568-2575.

Mclaren, A., Valdes-Solis, T., Li, G., & Tsang, S. C. (2009). Shape and size effects of ZnO nanocrystals on photocatalytic activity. Journal of the American Chemical Society, 131(35), 12540-12541.

Ngah, W. W., Teong, L. C., & Hanafiah, M. M. (2011). Adsorption of dyes and heavy metal ions by chitosan composites: A review. Carbohydrate polymers, 83(4), 1446-1456.

Nithya, R., & Ragunathan, R. (2011). Decolorization of the dye congo red by pleurotus sajor caju silver nanoparticle. In Int Conf Food Eng Biotechnol (Vol. 9, pp. 12-15).

Oliveira, L. V., Bennici, S., Josien, L., Limousy, L., Bizeto, M. A., & Camilo, F. F. (2020). Free-standing cellulose film containing manganese dioxide nanoparticles and its use in discoloration of indigo carmine dye. Carbohydrate polymers, 230, 115621.

Opoku, F., Kiarii, E. M., Govender, P. P., & Mamo, M. A. (2017). Metal oxide polymer nanocomposites in water treatments. Descriptive Inorganic Chemistry Researches of Metal Compounds, 173-199.

Prasanna, S. S., Balaji, K., Pandey, S., & Rana, S. (2019). Metal oxide based nanomaterials and their polymer nanocomposites. In Nanomaterials and Polymer Nanocomposites (pp. 123-144). Elsevier.

Rabeea, M. A., Owaid, M. N., Aziz, A. A., Jameel, M. S., & Dheyab, M. A. (2020). Mycosynthesis of gold nanoparticles using the extract of *Flammulina velutipes*, Physalacriaceae, and their efficacy for decolorization of methylene blue. Journal of Environmental Chemical Engineering, 8(3), 103841.

Ravishankar, T. N., Manjunatha, K., Ramakrishnappa, T., Nagaraju, G., Kumar, D., Sarakar, S., ... & Dupont, J. (2014). Comparison of the photocatalytic degradation of trypan blue by undoped and silver-doped zinc oxide nanoparticles. Materials science in semiconductor processing, 26, 7-17.

Roy, K., Sarkar, C. K., & Ghosh, C. K. (2015). Photocatalytic activity of biogenic silver nanoparticles synthesized using potato (*Solanum tuberosum*) infusion. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 146, 286-291.

Shahabuddin, S., Sarih, N. M., Ismail, F. H., Shahid, M. M., & Huang, N. M. (2015). Synthesis of chitosan grafted-polyaniline/Co_3O_4 nanocube nanocomposites and their photocatalytic activity toward methylene blue dye degradation. RSC advances, 5(102), 83857-83867.

Singh, R. L., Singh, P. K., & Singh, R. P. (2015). Enzymatic decolorization and degradation of azo dyes–A review. International Biodeterioration & Biodegradation, 104, 21-31.

Sirajudheen, P., & Meenakshi, S. (2019). Facile synthesis of chitosan-La^{3+}-graphite composite and its influence in photocatalytic degradation of methylene blue. International journal of biological macromolecules, 133, 253-261.

Sriramulu, M., & Sumathi, S. (2017). Photocatalytic, antioxidant, antibacterial and anti-inflammatory activity of silver nanoparticles synthesised using forest and edible mushroom. Advances in Natural Sciences: Nanoscience and Nanotechnology, 8(4), 045012.

Subramanian, V., Wolf, E., & Kamat, P. V. (2001). Semiconductor−metal composite nanostructures. To what extent do metal nanoparticles improve the photocatalytic activity of TiO_2 films?. The Journal of Physical Chemistry B, 105(46), 11439-11446.

Sudhakar, S., Jaiswal, K. K., & Ramaswamy, A. P. (2018). The Role of Microwave Irradiation Temperature on Nitrogen Doping in Metal-Free Graphene Catalysts for an Efficient Oxygen Reduction Reaction in an Alkaline Condition. ChemistrySelect, 3(31), 8962-8972.

Sudhakar, S., Jaiswal, K. K., Peera, S. G., & Ramaswamy, A. P. (2017). Green synthesis of N-graphene by hydrothermal-microwave irradiation for alkaline fuel cell application. International Journal of Recent Scientific Research, 8(8), 19049-19053.

Sulaiman, S. N. A., Noh, M. Z., Adnan, N. N., Bidin, N., & Ab Razak, S. N. (2018, May). Effects of photocatalytic activity of metal and non-metal doped TiO_2 for hydrogen production enhancement-a review. In Journal of Physics: Conference Series (Vol. 1027, No. 1, p. 012006). IOP Publishing.

Tamayo, L., Palza, H., Bejarano, J., & Zapata, P. A. (2019). Polymer composites with metal nanoparticles: synthesis, properties, and applications. In Polymer Composites with Functionalized Nanoparticles (pp. 249-286). Elsevier.

Uddin, M. J., Cesano, F., Bonino, F., Bordiga, S., Spoto, G., Scarano, D., & Zecchina, A. (2007). Photoactive TiO_2 films on cellulose fibres: synthesis and characterization. Journal of Photochemistry and Photobiology A: Chemistry, 189(2-3), 286-294.

Verma, R., Khan, A. B., Khan, M. I. K., Amar, A. K., Sah, S., Jaiswal, K. K., & Singh, R. K. (2021). Microwave-assisted biosynthesis of copper oxide nanoparticles using *Atalantia monophylla* (L.) leaf extracts and its biomedical applications. Chemical Engineering & Technology, 44(8), 1496–1503.

Virkutyte, J., Jegatheesan, V., & Varma, R. S. (2012). Visible light activated TiO_2/microcrystalline cellulose nanocatalyst to destroy organic contaminants in water. Bioresource technology, 113, 288-293.

Xu, C., Anusuyadevi, P. R., Aymonier, C., Luque, R., & Marre, S. (2019). Nanostructured materials for photocatalysis. Chemical Society Reviews, 48(14), 3868-3902.