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Nanoparticle synthesis advancements and their application in wastewater treatment: A comprehensive review

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The global water crisis requires effective wastewater treatment methods where conventional approaches often face challenges related to cost, recyclability, efficiency, and overall effectiveness. In this regard, the significantly small size, large surface area, and enhanced photocatalytic properties of recently developed nanoparticles have opened new avenues for wastewater treatment. This comprehensive review focuses on recent advancements in the synthesis methods for different types of nanoparticles and nanocomposites based on metals, carbon, polymers, waste materials, and zeolites which have highly sustainable and innovative results in wastewater treatment. The introduction of silver and gold nanoparticles has enhanced photocatalytic and biological activities. Similarly, zeolite and seaweed composites have exhibited efficient dye degradation capabilities. Eco-friendly carbon soot nanoparticles have shown promising biological activities, while nitrogen-doped carbon quantum dots have exhibited long-term stability for various applications. Additionally, waste material-based calcium oxide nanoparticles and carbon quantum dot-carbon nanotube nanocomposites have also shown enhanced dye degradation activities.

1. Introduction

Thinking of a world without water is as futile as a lab without equipment! The whole earth is an enhanced natural laboratory that nurtures life and water plays a fundamental base in this nurturing. Pure and fresh water is required not only for plants and human beings but also for necessary industrial processes such as agricultural activities, food and beverage industries, and other chemical industries. There are plenty of water resources and reserves on the earth yet every day the headlines break with some sort of scarcity or crisis all over the globe.[1–3] There are multiple reasons for the unfolding water crisis including climate change, uncontrolled population, fast-growing urbanization, agriculture enhancement, reckless industrialization, etc. Most of these factors increase water stress by consuming a hefty proportion of available water resources. These factors are also responsible for a disbalance in global wastewater management and repercussions are the pollution and contamination of existing water reserves.[4–7]

As per recent studies of the World resources institute, it is expected to have a more than twenty to thirty percent increase in global demand for water and around 5.7 billion people will face water stress for at least one month per year by the year 2050. In a time when the world is facing war and conflicts over water stress, the contamination and pollution in water reserves are creating major concerns as the deaths due to inadequate water consumption is rising day by day, and even by the time this paper is being written. The improper management of industrial and urban wastewater has caused severe contamination of the water reserves and millions of people are dependent on these chemically contaminated water resources. Contaminated water can spread various diseases such as typhoid, polio, hepatitis A, diarrhoea, dysentery, cholera, etc. As

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per the reports of the world health organization, almost 829000 people can die only due to diarrhoea developed by contaminated and unsafe drinking water.[8]

Water pollution has various causes and concerns but the most challenging is the industrial wastewater effluents which are either discharged into rivers or water reserves directly or with minimal treatment. These effluents contain a large number of organic compounds, harmful chemicals, dyes, high pH levels, heavy metals, dissolved salts, dissolved solids, ammonia, antibiotics, oil, fats, nuclear wastes, and other toxins which increase the turbidity in water reserves and affect the aquatic life by increasing BOD and COD which reduces photosynthesis and affects the plant growth. These disturbances in the water system further enhance bioaccumulation, toxicity, carcinogenicity, and mutagenicity.[9,10] Urban wastewater treatment has a history of more than 150 years and it is improving with time. The common methods for wastewater treatment are physical and chemical methods. Physical separation techniques such as adsorption, filtration, sedimentation, boiling, reverse osmosis, desalination, distillation, and light irradiation are included under physical methods while the chemical methods involve chlorination, flocculation, coagulation, ion exchange, etc. Although these methods have frequent uses yet they do not seem to be much effective and suitable for the degradation of heavy metal ions or toxic chemicals. Some other alternatives such as UV-light irradiation, incineration, or ozone treatments are also used but they are much more expensive in respect of frequent utilization and need of the hour.[11–13]

In addition to all these existing methods, researchers have found new advances in the form of nanomaterials which have given rise to economic, green, and much more sustainable aspects of wastewater treatment. The nanoparticles have their own unique properties due to their very small size ranging around 100 nm and less. These nanoscale structures have a high surface area which imparts distinct properties from the bulk materials. The nanostructures also possess different optical, electric, magnetic, photocatalytic, and biological activities along with distinct reactivity and stability. The nanoparticles are good adsorbents as they are less soluble in water and they have also proven to reflect impactful antimicrobial activities.[14–18]

Recent research has reported that both metal and nonmetal nanoparticles have remarkable impacts on wastewater treatment. The nanomaterials such as carbon-based nanoparticles, carbon nanotubes (CNT), carbon quantum dots (CQD), protein nanofibrils, nanocomposites, polymer-based nanoparticles, intrinsically conducting polymers (ICP), Schiff reagent coated nanoparticles, metals, metal oxide, and metal sulfide nanoparticles are being actively used in wastewater treatment. These nanomaterials can not only react and adsorb harmful chemicals, but they can also interact with microbes and destroy their growth by penetrating their cell membranes. Some nanoparticles such as Cu, CuO, Ag, Au, etc. have shown antimicrobial activity against pathogens which might impact their growth and control the spread of infectious diseases. These nanoparticles can interact with fungi, Gram-negative and Gram-positive bacteria thereby destroying their bacterial membrane.[19–24] Although the use of nanomaterials as waste adsorbers has grabbed mass attention over the decade yet its complexity, high cost, and energy requirements need to be balanced. In this aspect, multiple researchers are continuously working across the world which has given rise to some cutting-edge synthesis methods remarkably efficient in energy-saving, cost-cutting, green synthesis, waste degradation, and antimicrobial properties.[25]

2. Advance synthesis methods of nanoparticles

2.1 Synthesis methods of metal-nanoparticles

In metal nanoparticle synthesis methods, there are numerous advanced techniques such as microwave irradiation, chemical reduction, vapor depositions, hydrothermal, thermal and electrochemical deposition, or green synthesis, etc. which have shown new verticals to the synthesis approach. For example, Dar *et al.* synthesized unique crystalline copper nanoparticles under the microwave irradiation technique where the nanostructures were found to be surfactant free. In this synthesis, the copper nanospheres were synthesized by dissolving 52.8 mg of copper acetylacetonate in 100 mL of benzyl alcohol and exposing the solution to an 800 W microwave for 3 minutes under reflux conditions. Further, Al_2O_3 and SiO_2 substrates were inserted in 200 mL of 104.8 mg of copper acetylacetonate solution to support the Cu-nanoparticles. The HR-SEM and TEM reflect the size of Cu-nanospheres to be 150 nm diameter with 7 nm extensions of each nano-crystal. The special achievement of this synthesis is the stability of the Cu-nanoparticles against oxidation for several months under ambient air. The XRD pattern of Cu-nanoparticles as prepared and after 12 months of exposure are attached in **Fig. 1**.[26]

In the expectation of better green synthesis methods, Dhas *et al.* synthesized silver chloride nanoparticles using the marine algae, *Sargassum plagiophyllum*. The resultant nanoparticles have silver and silver chloride facets, and they have impactful activities against bacteria. In this synthesis, the algae samples were first dried for 8-10 days, powdered, and converted into a solution of 5 g powder in 50 mL of demineralized water. Further, the extract of seaweed solution and 5 mL of 1 mM silver nitrate solution were mixed and kept at room temperature for a time of 24 hours. The yellow-brown color change confirmed the formation of silver chloride (AgCl) nanoparticles which were further verified with characterization results. The HR-TEM image explained that the NPs were 18-42 nm in size. The stability of NPs is due to the binding of bioorganic materials on the surface. The XRD results confirmed the synthesis of AgCl-NPs. The synthesized silver chloride nanoparticles were found to be dose-dependent in an antibacterial test against *Escherichia coli*. The increasing concentration of nanoparticles increases the zone of inhibition. The analysis results are attached in **Fig. 2** and **Fig. 3**.[27]

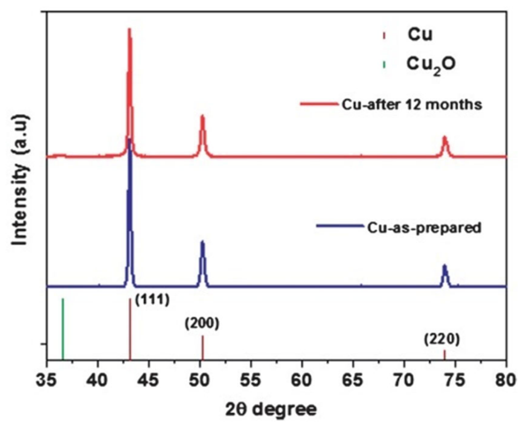


Fig. 1. Powder XRD patterns of copper nanostructures

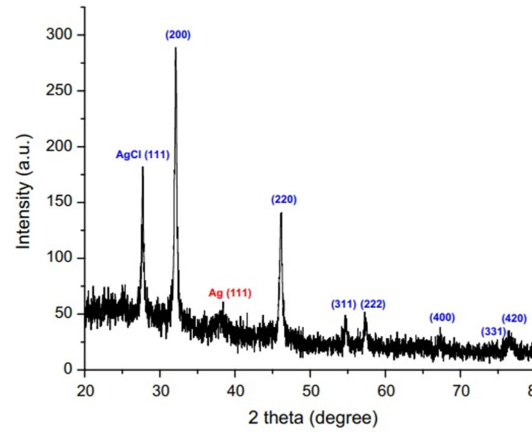


Fig. 2. XRD Peaks of Ag and AgCl-facets

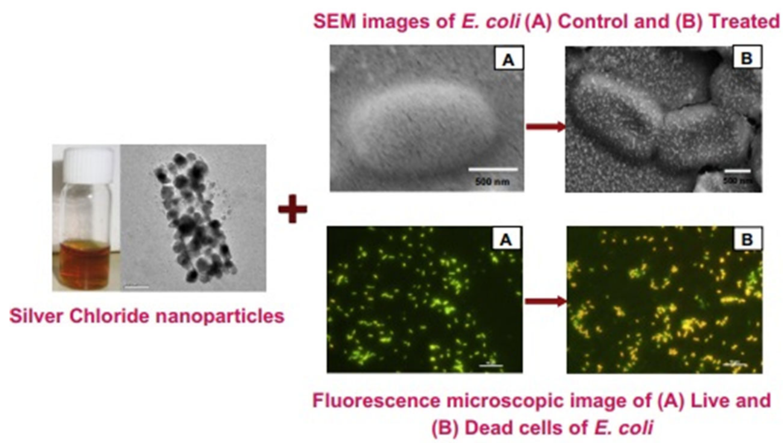


Fig. 3. Antibacterial activities of AgCl-NPs against *E.Coli.*

In other synthesis approaches, Ismail *et al.* applied the pulsed laser ablation technique to synthesize magnetic iron oxide nanoparticles. In this method, the iron target was placed in dimethylformamide and sodium dodecyl sulphate solutions. The synthesized alfa-Fe_2O_3 nanoparticles showed significant inhibition on the strains of both the gram-positive and gram-negative bacteria.[28] Pathak *et al*. synthesized ZnO nanoparticles doped with Ag, and Au at a concentration of 2 mol% via combustion. The zinc nitrate, silver nitrate and tetra chloroauric-III-acid hydrate were mixed with urea in 5mL water and stirred till the solution was transparent. The solution was then heated for 30 minutes at 80^0C to obtain the gel which was further heated in a muffled furnace at 500^0C. The effect of doping was investigated on the photocatalytic and antimicrobial properties. The results reported that metal doping did not alter the structure of ZnO nanoparticles. The doping agents did not mix uniformly and thus surrounded the nanoparticles inside the matrix. Both the doping agents (Ag and Au) have shown impactful photocatalytic and biological activities. The given **Fig. 4** explains the photocatalytic activities of both the pure and doped zinc oxide nanoparticles and **Table 1** shows their impact on the microbes.[29]

Table. 1. Impact of Nanoparticle samples on microbes

Sample	Inhibition zone average (radius in mm)		
	E. coli	*S. aureus*	*E. ashbyii*
ZnO	5.25	8.5	7.5
ZnO: Ag	4.3	7.0	9.75
ZnO: Au	3.8	5.5	6

Photocatalytic efficiency of ZnO and doped ZnO

Kumar *et al*. synthesized copper oxide nanoparticles through microwave mediation which was more economical and colloidally stabilized with antibacterial properties. The CuO-NPs were prepared from glucose, starch, and $CuCl_2$ via microwave mediation. In this method, the screening test was optimized by response surface methodology where the CuO nanoparticles were produced with varying $CuCl_2$ concentrations at a fixed time. The obtained CuO-NPs reported significant antibacterial activity when applied against the spore-forming bacteria and both the gram-negative and gram-positive bacteria.[30]

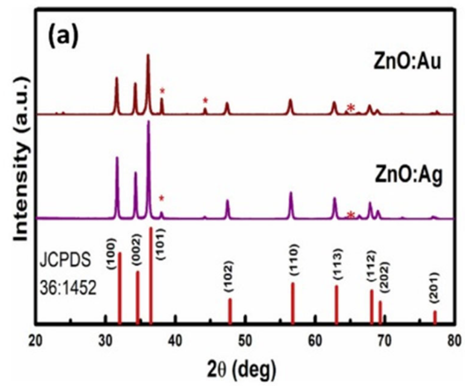


Fig. 4. XRD of Ag and Au-doped ZnO where the asterisk peaks are NPs of metal dopants.

Das *et al*. used the extracts of *Jatropha curcas* latex and *Cinnamomum tamala* leaves to synthesize the magnetite nanoparticles coated with natural products. The synthesis was applied under an open-air reaction environment through co-precipitation. In this method, the JC and CT extracts were prepared and their fixed concentrations were poured into the solution of a fixed proportion of anhydrous $FeCl_3$ and $FeCl_2.2H_2O$ in deionized water (stirred for 30 minutes). Sodium hydroxide was added to this solution mixture for precipitation purposes and the mixture was further stirred till the precipitate formed. The nanoparticles formed under this method had 26-35 nm size for the CT coated-Fe_3O_4 and 20-42 nm for JC-coated Fe_3O_4-nanoparticles which reflected impactful dye adsorption and antibacterial activities. **Fig. 5** shows the antibacterial activities of nanoparticles.[31]

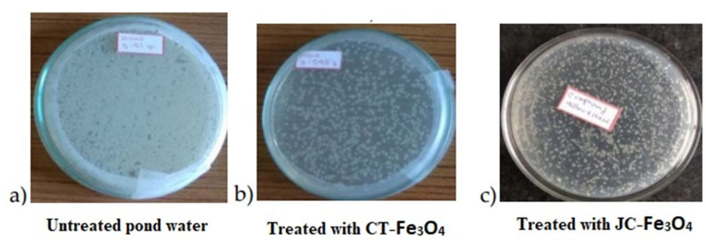


Fig. 5. Antibacterial activities of nanoparticles

Vinh Tien Nguyen synthesized silver nanoparticles by mixing pomelo peel extract called PPE with $AgNO_3$ under sunlight energy. In this process, the pomelo peel was mixed with a citric acid solution and treated at a temperature of 85°C for a time of 2 hours. This extract was then treated with silver nitrate solution under exposure to sunlight. The synthesized silver nanoparticles were more stable toward electrolyte-induced aggregation and reflected good biological activities. The given **Fig. 6** reflects the UV-visible spectra of the appearance of pomelo peel extract after 30 minutes of exposure under different temperatures and sunlight conditions.[32]

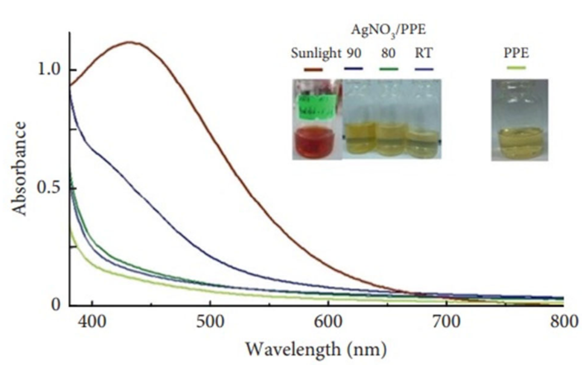
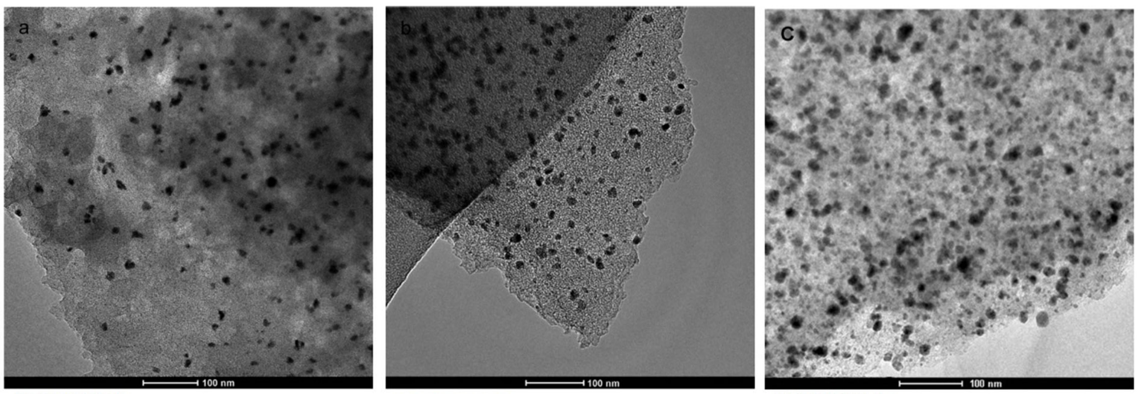


Fig. 6. UV-vis spectra of PPE and $AgNO_3$/PPE

Hung *et al*. used the stirring method to synthesize tungsten-modified nanocomposites with titanium oxide and silicon oxide. In this method, a mixture of titanium (IV) oxysulphate and ammonium metatungstate with silicon oxide was hydrolyzed under an alkaline medium and the mixture solution was stirred till the composites formed. The resultant catalyst nanocomposites showed a 9 times higher photocatalytic activity with dyes under visible light.[33]

2.2 Synthesis methods of carbon-based nanoparticles

In general, carbon-based nanoparticles have been found to have lower toxicity in comparison to metal nanoparticles and so they have recently got much more attention from researchers. In a particular nanocomposite synthesis, Gong *et al.* applied the atomic layer deposition method for the synthesis of uniform Pd-nanoparticle catalyst over the activated carbon supports. The precursors used in this method are HCOH and Pd(II)hexafluoroacetylacetonate. The nanoparticles obtained had a uniform size and were found to be evenly distributed on the support. The given **Fig. 7** shows the TEM image of Pd-nanoparticles that are sub-ported on untreated AC. It was found that the increasing ALD cycles increased the density of Pd-nanoparticles.[34]



(a) AC-Pd-ALD 1c (b) AC-Pd-ALD 2c (c) AC-Pd-ALD 3c

Fig. 7. TEM images of ALD Pd-NPs subported on untreated AC

Roonansi and Mazinini synthesized barium ferrite and activated carbon nano-composites which could be applicable as the photocatalysts for the degradation of organic dyes. In this synthesis, the 2:1 molar ratio of ferric and barium nitrates was dissolved in water and maleic anhydride was added as a complexing agent in 1:2 ratio to the nitrates at 60^0C, and the activated carbon was added to this mixture. The AC was added in such proportion that it could obtain the composite of AC to barium ferrite in 1:2 mass ratio. The suspension was kept under stirring till the temperature is homogenized and the concentrated gel is formed. Finally, the gel was heated at 400^0C temperature for 30 minutes and the obtained sample was powdered. The results analyze that the introduction of activated carbon increases the photocatalytic reactivity of the composite against organic dyes.[35]

Pal *et al.* synthesized multicolor fluorescence surface passivated carbon dots (CDP) from curcumin. In this synthesis, 0.3 g curcumin and a solution containing 60 mL water and 20 mL ethanol were mixed followed by the addition of 0.4g of polyethyleneimine (PEI), and the mixture was stirred for 30 minutes at a temperature of 80^0C. The color of the solution was changed from yellow to red. The solution was further processed to hydrothermal conditions at 200^0C under 15kg/cm^{2}g pressure in the presence of nitrogen for a time period of 12 hours. The solution obtained was dark brown which was further cooled and centrifuged at 15000 rpm for 30 minutes to obtain PEI passivated carbon dots. The characterization results confirm the size of carbon dots to be in the range of 2-3 nm and the shape to be nearly spherical. These carbon dots have been proven to be very much efficient in bioimaging and various bio-applications. The use of such carbon dots can be more interesting in wastewater treatment.[36]

In search of a greener approach, Nadeem *et al*. used vegetable oil soot to synthesize the carbon nanoparticles free from catalysts. In this synthesis, the oils extracted from mustard, olive and linseed were combusted in a clay lamp and the soot was collected and purified for controlled synthesis of carbon nanoparticles. The average nanoparticle size was 18 nm for mustard oil, 24 nm for olive oil and 57 nm for linseed oil. These nanoparticles showed excellent antibacterial activities.[37]

2.3 Synthesis methods of polymer-based nanoparticles

Polymer-based nanoparticles show advanced biocompatibility in comparison to metal or carbon-based nanoparticles and so they have gained much appreciation in wastewater treatment and for other biological activities. In this aspect, Wang *et al.* used the hydrothermal method to synthesize the chitosan-based blue-green fluorescent carbon nanoparticles. In this synthesis, 50 mL of DI water was used to dissolve 1g of chitosan solid followed by heating the solution for 10 hours at 200^0C temperature. Further, the sample was cooled to room temperature and filtered. The sample was then processed to the dialysis for a time period of 8 hours with a membrane of 1000 molecular weight. In this process, the water was changed in every four hours. Finally, the solution was frozen at a temperature of -80^{0}C and the chitosan-carbon NPs were obtained from the dryer in the form of powder. These nanoparticles reported a removal efficiency of about 54.6 % for heavy metal ions from wastewater which is much higher than normal carbon dots.[38]

Kumaresan *et al.* synthesized polymer-supported $NiWO_4$ nanocomposites which were capable of degradation of toxic dyes under visible light. In this synthesis, the hydrothermal method is used to composite polyaniline (PA) and polypyrrole (PPy) with $NiWO_4$ nanomaterial. The results reported that PA-$NiWO_4$ composites have better efficiency in the degradation of dyes, and they can be recycled in multiple cycle. These nanocomposites degraded around 94.5 % of crystal violet and 91.5 % of methylene blue. **Figure (8)** shows the degradation percentage of crystal violet and methylene blue dyes for 5 cycles under PA-supported $NiWO_4$ nanocomposites.[39]

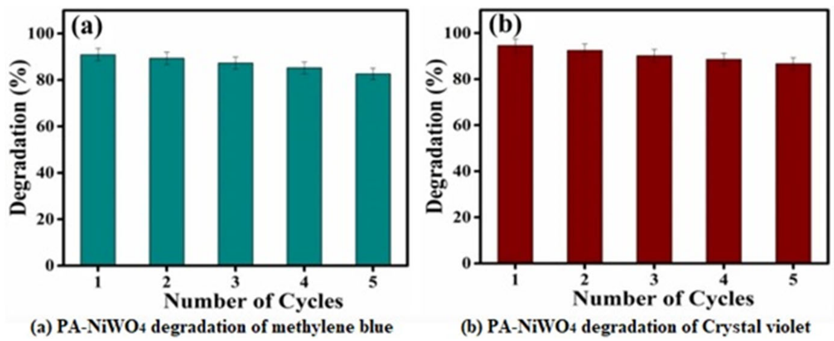


Fig. 8. Degradation of (a) Methylene blue and (b) Crystal violet by PA-$NiWO_4$

Nitin Chandra Joshi and Neelam Kumar synthesized polymethyl methacrylate (PMMA) and ZnO nanoparticles-based nanocomposite. In this synthesis,0.1 molar ethanolic solution of zinc acetate was stirred for a time period of 45 minutes followed by adding a few drops of 8.2 M concentrated NaOH. The reaction mixture was further stirred for a time period of 30 minutes and the collected ZnO-nanoparticles were first washed followed by drying. Further, a 7.5 mL solution of MMA was mixed with a solution of 15 mL chloroform, benzoyl peroxide and 1 g of ZnO-Nps. This mixture was further stirred for a time of 10 hours at a very low temperature of 2^{0}C and the resulting solution of PMMA-ZnO was dried. The PMMA/ZnO composites are found to be highly efficient in adsorbing toxic heavy metal cations such as Cr^{+6}, $Cd^{+2,}$ and Pd^{+2} under the optimized conditions of 60^{0}C temperature, pH 6, and 60-min agitation.[40]

Singh *et al*. synthesized a ternary nanocomposite (ZCP) from activated carbon (AC) fabricated with zinc oxide (ZnO) and polypyrrole (PPy). In this synthesis, the brown rice husk was used as an AC precursor. The carbonization of the husk and polymerization was performed in an acidic medium and the nanocomposite was prepared using the hydrothermal method. The resulting ZCP nanocomposites were efficient in degrading organic dyes such as methylene blue. The degradation efficiency was reported to be 98.12% at room temperature under visible light within 20 minutes while it was increased to 99.05% at high temperature.[41]

2.4 Synthesis methods of waste material-based nanoparticles

Waste material management has always been a concern for new-age researchers. In this regard, when a few waste materials were used to produce certain new useful nanoparticles, they gathered positive attention and recognition from the global research communities. In this approach, Mohamed *et al*. applied the thermal decomposition method to synthesize the calcium oxide and (CaO/C) nano-powders. The eggshell and coffee wastes were used as the precursors for this synthesis. The spent coffee grounds (SPG) were used to synthesize the activated carbon and eggshell for calcium content. In this process, 40 g of SPG and 40 g of eggshells were mixed together, and the mixture was calcinated under 900^{0}C for 4 hours in a furnace in atmospheric pressure. The resultant CaO and CaO/C nano-powders were tested for photocatalytic activity against the methylene blue dye when exposed to sunlight for a time period of 35 min. The results showed that the increase in the surface area enhances the photocatalytic efficiency and dye adsorption.[42]

Chen *et al.* synthesized carbon quantum dot (CQD)-carbon nanotubes (CNT) composites from the waste eggshell-derived catalysts under a one-step chemical vapor deposition method. The resulting CQD-CNT composites have a very large surface area, surface functional groups, and surface structures in comparison to the defective carbon nanotubes. The adsorption of methylene blue dye on quantum dot-CNTs has been found to be 99.5% which is 4.6 times higher than pristine CNTs and 1.3 times higher than defective CNTs.[43] Kammah *et al.* used water treatment residues to synthesize a novel, eco-friendly, and economical adsorbent nanoparticle via high energy ball milling method. In this method, the water treatment residue (WTR) was first collected and sieved with the help of two mesh sizes 2millimeter and 51 micrometer. The WTR fractions passing through the mesh with 2 mm size was collected and mentioned as bulk residue sample while the fractions passing through 51 micrometer mesh was selected for nanoscale production. The later sample was then processed to ball mill where it undergoes grinding to produce nano sized WTR. The resultant nanoparticles have been found excellent in the degradation of indigo carmine (IC) dye inside the contaminated water.[44]

Rani *et al.* synthesized fabricated nitrogen-doped carbon quantum dots (NCQD) nanoparticles from empty fruit bunches (agricultural waste) using the hydrothermal method. The obtained NCQD particle size is 3.2 nm and it performed strong photocatalytic activity against methyl green dye. Almost 99% of the dye was degraded under UV irradiation. The particles showed outstanding stability and reactivity in fluorescent properties even after 12 months of storage.[45]

2.5 Synthesis methods of zeolite-based nanoparticles

Recently zeolite and zeolite-based nanoparticles have received much attention due to their unique structure and properties such as high surface area, chemical stability, selective adsorption, ion-exchange capacity, and biocompatibility, etc. suitable for wastewater treatment. In this regard, Tauanov *et al.* synthesized a new zeolite nanocomposite from the coal fly ash precursors using an alkaline-based hydrothermal method. In this synthesis, two types of fly ash samples were taken: K-coal fly ash and M-coal fly ash. These samples were separately processed in a heavy-walled hydrothermal reactor with a one-liter capacity. The setup was introduced with 3M sodium hydroxide solution for activation and the temperature was maintained at 110^0C. The setup was kept for 48 hours under 125 rpm conditions followed by filtration of the final mixture till the neutralized pH is achieved. The obtained zeolite fly ashes were dried and stored. Further, 1.0 g of zeolite samples were mixed with 10 mL of $AgNO_3$ solution at 3 mM concentration and processed for an ion-exchange reaction where the silver ion zeolite fly ash samples were obtained which were reduced to silver nanoparticles using an excess concentration of $NaBH_4$. For further reference, the obtained silver-doped zeolite nanocomposites were marked as Ag-K-zeolite and Ag-M-zeolite. In order to understand the adsorption efficiency for iodide ions, about 0.2 gram of nanocomposite was dissolved in 40 ml of iodide solution and the kinetic was observed for around 168 hours. The results show that the nanocomposites have iodide removal efficiency of about 94.85% with the average capacity of 20mg iodide saturation per gram composite. The logarithmic curves of adsorption kinetics explains that the adsorption rate was way faster in Ag-K-Z composite than in Ag-M-Z composite. The adsorption graph is shown in **Fig. 9**.[46]

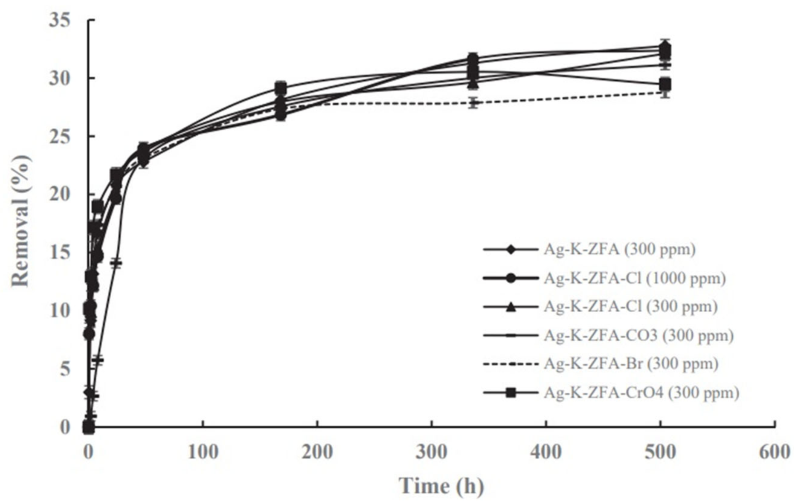


Fig. 9. Adsorption kinetics of iodide using both the ZFA-Nanoparticles

Abdelrehman *et al*. synthesized some different types of nano zeolites and geopolymers with the help of rice husk and the waste cans that are made up of aluminium. These waste materials have been used as precursors of ash, aluminium ad silicon. The method showed to be economical and appealing. In this synthesis, two types of solutions were prepared- (1) Si-solution with the help of refluxing rice husk ash in NaOH solution and (2) Al-solution via dissolving the cans in NaOH. The Al-solutions were made with different concentrations so as they were labelled as Al-1, Al-2 and Al-3. In further step the Al-solution was added dropwise to the Si-solution and stirred for almost 1.5 hours' time duration followed hydrothermal processing and non-hydrothermal processing till the white precipitate obtained.

The synthesized nanoparticles were named as H1, H2 and H3 for hydrothermally produced samples and G1, G2, G3 for the samples without hydrothermal processing. The zeolite products H1, H2 and H3 have crystal size as 27.65 nm, 41.85 nm and 66.01 nm respectively while the geopolymer products G1,G2 and G3 have crystal size as 58.44 nm, 25.58 and 20.26 nm respectively. These zeolite nanomaterials have shown strong efficiency in removal of toxic metal ions such as (Cu^{+2},Co^{+2} and Zn^{+2}) from wastewater.[47]

Gayatri *et al*. synthesized zinc oxide-zeolite nanocomposite with the help of simple sol-gel method. In this synthesis the synthetic zeolites were first crushed and then activated under oven at a temperature of 110^0C followed by treating with HCl and washing with distilled water until the pH is neutralized and finally the activated zeolites were filtered and dried. In next step the zinc acetate and activated zeolite were mixed in 2:1 ratio and dissolved in 99% concentrated ethanol solution followed by heating and stirring. The solution obtained was stabilized for 12 hours and then filtered and dried. The obtained ZnO based zeolite nanocomposites had a pore size of around 4.42 nm and the crystal size of around 32.87 nm. The nanocomposites were capable of degrading procion red dye under UV-light and degradation efficiency was obtained as 90.42% under 2-hour time duration. **Fig. 10** shows the comparison of dye degradation efficiency of ZnO nanoparticles, synthetic zeolite and ZnO based zeolite nanocomposite where the newly synthesized nanocomposites have shown the maximum efficiency.[48]

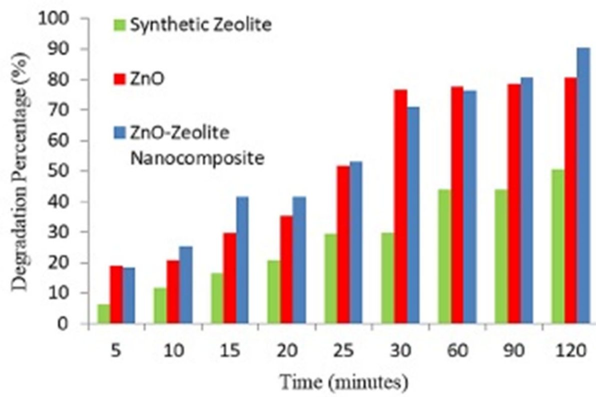


Fig. 10. Photodegradation of porcion red under UV-lamp

Hamd *et al*. synthesised a new zeolite nanocomposite based on green seaweeds algae with the help of wet impregnation method in which 1 g zeolite was mixed with 1 g green seaweed algae in 20 mL of deionized water and stirred at 500 rpm on a magnetic stirrer for one hour and the process was repeated thrice after which the obtained nanocomposite solution filtered, washed and dried. The characterization results showed that the Z-SG nanocomposite has 40.2 nm size and they were able to remove 91. % of congo red dye from wastewater with a capacity of 19.70 mg/g. This capacity is much more efficient than zeolite nanopores or seaweed nanoparticles.[51]

3. Conclusion

This review paper highlights some advanced nanoparticle synthesis methods involving greener, less toxic, energy saver and economic approaches. The involvement of green extracts like alga, *Jatropha curcas*, *Cinnamomum Tamala*, and pomelo peel extracts has shown significantly improved dye degradation, antibacterial and photocatalytic activities of the synthesized nanoparticles in comparison to the conventional methods. The nanoparticles derived from vegetable oil soot, egg shells, coffee wastes, rice husk, agricultural wastes, etc. are daily-life products and waste materials which incorporate a new way to synergize waste management and wastewater treatment, presenting an effective solution. This review will provide an enhanced sight for further research into the potential application of organic wastes or residues in designing more advanced, sustainable, and eco-friendly nanoparticles with enhanced activities.

Conflicts of interest

There are no conflicts to declare.

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