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Review Article: Review on Green Synthesis of Iron-Based Nanoparticles for Environmental Applications

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ABSTRACT

The use of effective and environmentally acceptable synthetic processes or procedures for the synthesis of nanomaterials is expanding substantially as a result of the nanotechnology relevance and its influence on numerous disciplines, as seen in the recent advancements in the field. This paper is a review of the published literature on the subject of environmentally friendly production of iron-based nanoparticles. In contrast to many conventional methods for the nanomaterials synthesis, the plant-mediated synthesis appears to be a highly intriguing and ecologically benign method. This is because of its simple methodology and eco-friendly approach. The created nanoparticle is simpler to manufacture, more stable, and effective in a range of application areas, as compared with conventional methods of synthesis. As a result, this analysis includes details on the various sources used so far and how the materials were created to be used in environmental applications, paying particular focus on the iron-based nanoparticles.

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Content

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1. Introduction

Nanotechnology, one of today's cutting-edge, multidisciplinary disciplines, is presently getting a lots of attention and has a big impact on pharmacology, the environment, and agriculture. The frequent contamination of aquacultures has led some authors to concentrate substantially on using nanotechnology to eliminate these pollutants [1]. Nanoparticle research has gotten a lot of attention because of its incredibly small size (in nm) and high surface-to-volume ratio, which causes physical and chemical alterations in their properties when compared to other substances with the same chemical composition. Furthermore, they are employed in environmental remediation methods such as heavy toxic metal and pollutant removal, as well as other contamination remediation [2]. Their nanoscale size makes them excellent for use in various industries, including heavy industry, commodity production, medical, chemistry, environment, energy, and agriculture. The two distinctive approaches for the NPs amalgamation are "top-down" and "bottom-up." The appropriate bulk material is reduced in size utilizing different methods, including as grinding, milling, sputtering, thermal/laser ablation, etc. in the top-to-bottom method. While in the bottom-to-top approach, NPs are synthesized by using chemical and biological methods by self-assembly of atoms to new nuclei, which grow into nanosize particles, whereas the “bottom-up” methods include chemical reduction, electrochemical methods, and so no decomposition [3]. The creation of an eco-friendly method for the nanoparticles synthesis is crucial because physical and chemical methods of synthesis have significant drawbacks like poor surface formation, low production rate, high cost of production, high energy requirements, and the use of toxic reducing agents. The use of biologically active chemicals, such as enzymes, which serve as reducing and capping agents, the possibility of large-scale manufacturing, and the use of less energy are all benefits of the biological synthesis process. For the synthesis process, a wide range of biological sources including microorganisms and plant components have been utilized. The significant limitations of microbe-mediated synthesis include the need to maintain cell cultures and work in an aseptic environment. Consequently, it has been determined that plant-mediated synthesis is the most advantageous strategy [4]. Adsorption by using various adsorbents is the most effective method for treating wastewater contaminated by heavy metal ions [5].

Because iron is the second most abundant element on the earth, the iron-based nanoparticles are important among synthesized nanoparticles due to their magnetic property, catalytic activity for removing pollutants from water bodies, low cost, high surface area, high degree of functionalization, high adsorption capacity for several contaminants in water and wastewater treatment, and notable antimicrobial and antioxidant activities [6].

It was discovered that the number of publications increased significantly and steadily between 2016 and 2021, indicating that this topic has lately come to the attention of wastewater treatment experts. However, because of the above mentioned excellent qualities, iron-based nanoparticles need to be extensively explored and reviewed. This review evaluates the key traits, thorough synthesis procedures, environmental application, and contaminant removal abilities of iron-based nanoparticles in wastewater. In addition, the restrictions on iron-based nanoparticles for contaminant removal are also addressed.

Many researchers have reported iron nanoparticles synthesis from various plant sources. The plant-mediated iron oxide nanoparticles were synthesized by using chloropytum comosum leaf extract. The acquired nanoparticle employed for the methyl orange de-colorization and antibacterial purposes [7].

Tea extract (polyphenols) used to create green iron nanoparticles, which were then carefully removed from cationic dyes during a 12-minute period with a solid-liquid ratio of 1:20. The green tea (Longjing) (Camillis Sinensis (L.) O. Ktze), which has the highest polyphenol content, serves as both a capping agent and a reductant to create Fe nanoparticles [8]. According to the author, the prepared complex has a regular spherical or ellipsoidal shape and is amorphous in the environment. Furthermore, the organic compounds produced from the tea extract surround the surface of the Fe nanoparticle, helping to preserve stability and dispersibility. It is reported that cationic dyes like malachite green (MG) and methylene blue can be removed from wastewater by using Fe nanoparticles-GT with a good selectivity and a high rate (MB) [9]. Nephrolepis articulate extracts were used to create iron-based nanoparticles.

The characterization analyses showed that the iron-based nanoparticles had spherical cores with sizes ranging from 40 to 70 nm, and the predominant types of iron present were FeO, iron oxides, and FeOOH. The significant reactivity of this recently created material was demonstrated by a subsequent assessment of the capacity of these iron-based nanoparticles to remove Cr (VI) solution. This work provides an appealing method to treat water tainted with chromium and synthesizing green nanoparticles. The aqueous leaf extract from D. mezereum was used to create iron oxide nanoparticles without the need of any other chemicals. The findings of the study which were supported by the report indicated that the D. mezereum leaf extract compound had a significant impact on the nanoparticles stability and the results of the study where showed that synthesized IONPs were the simpler catalyst to degrade MO dye so that 75% of total dye with 20 mg per liter initial concentration was removed after only 6 h within the solution containing 10 mg the IONPs with H_2O_2 [10]. Overall, the author contends that the environmentally friendly synthesis of iron oxide nanoparticles has the potential to become an effective, affordable, and practical method for a variety of future scientific and technical applications, such as the removal of toxic organic contamination from the environment. In another work, water and the plant surfactant Sapindus mukorossi were used to create hexacayano ferrite nanoparticles. The created nanoparticles were tiny and had distinct morphologies, such as hexagonal, rod, rhombus, and spherical shapes. The benefits of this technique include easy replication, low cost, and environmental friendliness. The dangerous PAHs BaP, chrysene, fluorene, phenanthrene, and anthracene were found to be present in the simulated water and soil, and these FeHCF nanostructures were discovered to be a possible catalyst in the treatment of these

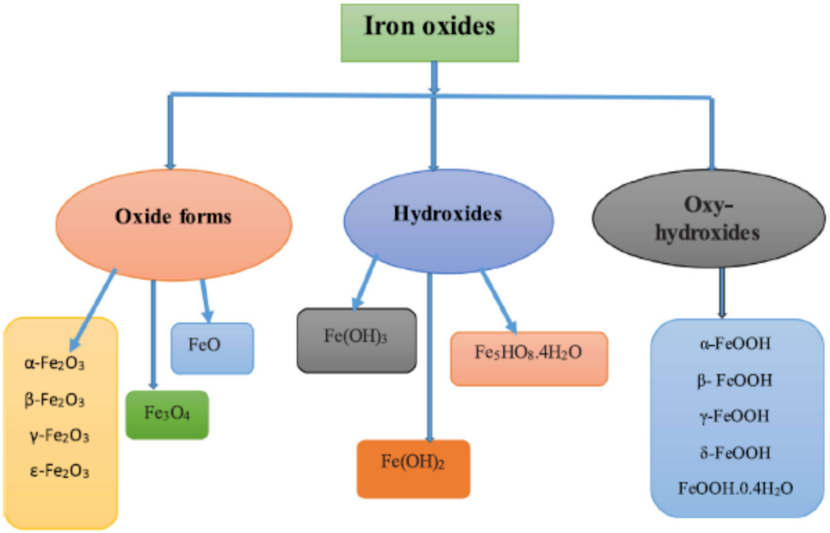

Figure 1. The basic form of iron based nanoparticles: oxides, hydroxides, and oxy-hydroxides

substances. [11]. Herein, some examples of the recent research results were presented that went beyond the conventional and outdated technologies by explicitly incorporating into their design elements to (l) decrease the usage of harmful and depleting material inputs, (2) increase the effectivity of time, space, and energy, and (3) develop iron based nanoparticles for environmentally friendly solutions and the application of the synthesized nanoparticle in environmental application was also addressed.

2. Types of Iron-Based Nanoparticles

Due to their better physicochemical qualities compared with bulk particles, iron-based nanoparticles (NPs) are manufactured and employed significantly as nanotechnology advances [12]. Iron oxides are a combined term for oxides, hydroxides and oxy-hydroxides made up of Fe (II) and/or Fe (III) cations andO^{2-} and /or OH^- anions. Currently, sixteen pure phases of iron oxide are acknowledged as displayed in **Figure 1**. These are Fe $(OH)_3$, Fe $(OH)_2$, $Fe_5HO_8•4H_2O$, Fe_3O_4, FeO, five polymorphs of FeOOH, and four of Fe_2O_3. Magnetite (Fe_3O_4), magnetite, and hematite are the most known oxide forms of Iron. Researches on the Zerovalent iron oxidation or aging have so far acknowledged several products, including goethite, akaganeite, lepidocrocite, magnetite, maghemite, green rusts I/II (a group of bluish-green Fe(II)–Fe (III) hydroxyl salts), siderite ($FeCO_3$), iron sulfide, etc. In addition to the above oxyhydroxides forms, feroxyhyte and ferrihydrite, better recast as $FeOOH•0.4H_2O$, and high-pressure FeOOH is another oxide/hydroxide form of iron oxides. Iron oxide nano-adsorbents such as hematite, maghemite, and magnetite (Fe_3O_4) have been widely utilized by researchers for the removal of various pollutants such as As(V), Cr(VI), $Cr_2O_7^{2-}$, MnO_4, Cu(II), Pb(II), and Hg(II) from the environmental or industrial effluents [13].

3. Systems for Green Synthesis of Iron-Based Nanoparticles

3.1. Green synthesis by using microbes

The advantages of microorganism-based nanoparticle synthesis over the traditional chemical syntheses have attracted attention in recent years. These benefits include energy-efficient synthesis at temperature, consumption of less harmful chemicals and byproducts, abundant natural resources, straightforward proportions, and the capacity to withstand adverse conditions. Fungi, bacteria, and yeast are examples of microorganisms producing nanoparticles through either an external or intracellular method. These processes involve the enzymatic reduction of metal ions, resulting in well-dispersed nanoparticles with a narrow size range. Proteins, peptides, and genes serve as natural capping agents, providing stability and preventing nanoparticle aggregation in turn. The metal ions diffuse into the cell, unlike the extracellular method, which includes enzymatic reduction of metal ions that are electrostatically bound to the cell wall or the surface of microorganism, the metal ions diffuse into the cell where they react with enzymes to make nanoparticles in intracellular mechanism [14].

With the aid of grown strains of the micro bacterium marinilacus that were discovered in sediment samples taken from the Damodar River in India, the magnetic iron oxide nanoparticles with an average particle size of 32–48 nm were created. The isolated bacteria was cultured with 1 mM of the precursor solution (ferric chloride solution), which resulted in the nanoparticles creation as evidenced by a 2 h color change of the culture from brown to dark brown. The culture was centrifuged; the supernatant was separated, separated, dehydrated, and described by using scanning microscopy to separate the produced nanoparticles from cells [15].

3.2. Green synthesis by using Biomolecules

A straightforward and adaptable technique of nanoparticle manufacturing and enzyme catalysis employed a common platform, poly (acrylic acid)-coated polyvinylidene fluoride membrane, and environmentally friendly procedures. The enzymes maintained a high activity upon immobilization that was equivalent to homogeneous phase catalysis and were integrated into the polymer multilayer-assembled membranes through the electrostatic interactions. The reaction yields can be adjusted by modifying parameters like the enzyme loading on each membrane and the residence period, which is connected to permeate flux. Membranes carrying different enzymes can be stacked and utilized as reactors in series. In a membrane domain, we have achieved the direct and environmentally friendly production of bimetallic Fe/Pd particles. Ascorbic acid, a biodegradable substance, is used in this procedure as opposed to the conventional method, which uses hazardous sodium borohydride [16].

3.3. Green synthesis by using plants and phytochemicals

The efficient extraction of the bioactive components of the plant materials is essential to the process of creating iron-based nanoparticles from plant materials like leaves, stems, or roots. These substances include water-soluble polyphenols, saponins, organic acids, vitamins, and polysaccharides as well as some organic solvents like acetone and methanol. Then, they react with a precursor, primarily an iron (III) chloride solution, acting as capping and reducing agents. Zero-valent ion nanoparticles are created when Fe3+ is reduced to Fe0 [14]. For instance, polyphenols from dried green tea extract were used to generate zero-valent iron. Green tea leaves were microwave-extracted for polyphenols, which plentiful bioactive chemicals are found particularly in the leaves of numerous plants, which were used to produce nanoparticles with particle sizes ranging from 8 to 23 nm. The powdered green tea leaves were extracted with ethanol, allowed to cool, and then filtered. Plant extract containing polyphenols was reacted with iron (III) chloride solution to synthesize zerovalent iron nanoparticles. A summary of plant-based procedures for the nanoparticles synthesis is provided in the following [17]. The nanoparticles production by plants is superior to that of biomolecule, bacteria and fungi since the latter requires constant sterile conditions and requires labor-intensive high maintenance cultures [18].

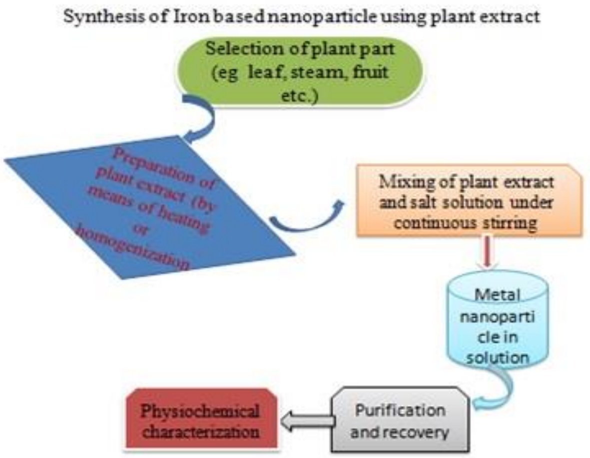

Figure 2. Green Synthesis procedure for iron and iron-based nanoparticles

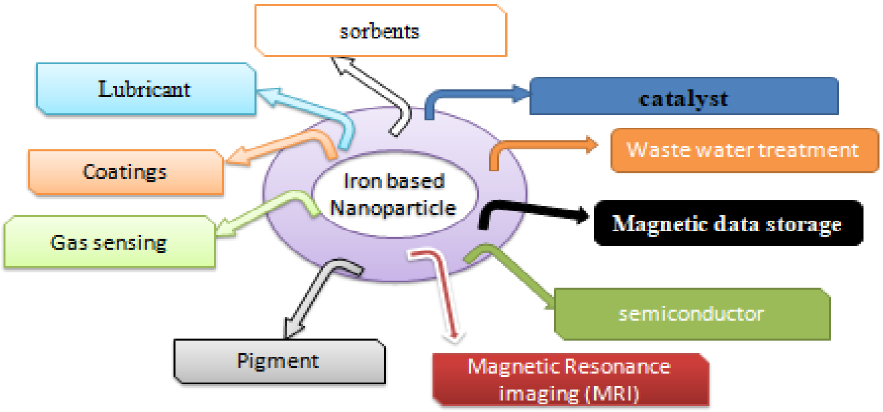

Figure 3. Application of iron-based nanoparticle

3.4. Green synthesis procedure

The common procedure involved in the green synthesis process of iron and iron-based nanoparticles is given in **Figure 2**.

4. Applications of Iron-Based Nanoparticle

The iron and iron-based nanoparticles have a good range of applications like environmental, biomedical, textiles, health care, food industry, electronics, renewable energy, etc. A number of the applications are given in **Figure 3**.

One of the early applications is the metal and dye removal from wastewater and spring water by using adsorption studies. Consequently, the earlier research projects was carried out in the relevant field to date and their findings achieved by using naturally synthesized iron and iron-based nanoparticles, are thoroughly discussed as follows [4].

Due to the depth to which magnetic resonance imaging (MRI) penetrates the clinical diagnosis process, this field of study has been extensively investigated. The green approach can be used to create high-quality FeNPs at a minimal cost. The surface properties of nanoparticles may be controlled, and this allows for drastically improved MRI imaging that is extremely delicate. The quick exchange of 1H's is encouraged by the surface construction of iron-based MNPs, which also increases the diffusion velocity between the bulk stage and layer enclosing the MNPs [19]. Iron nanoparticles are well suited for use in wastewater treatment because of their high surface to volume ratio, high sensitivity and reactivity, high adsorption capacity, and ease of functionalization [20].

The iron nanoparticles contain high surface area that offers a higher catalytic activity. Owing to their extremely large surface to volume ratio, the nanoparticles play a role as an efficient catalyst in the chemicals production. Iron-based nanoparticles have shown termondeneous application in multidisciplinary areas. For example, it is used as a catalyst material adsorbent in water and wastewater treatment, as a pigment in the manufacturing industry. Moreover, they are essential in the protection of environmental pollution or environmental application [4].

5. Green Synthesized Iron-Based Nanoparticles in Environmental Application

An effective and ecologically responsible technique for synthesizing nanoparticles should ideally use renewable energy, decrease waste discharge, and optimize energy utilization, according to the principles of green chemistry. This means that the active bio-component for the green synthesis process should be derived from plants, microbes, bio-polymers, and waste materials, with little heating and solvents. Water is considered the universal solvent and has been utilized in various experiments to dissolve biomolecules, especially polyphenols extracted from plants and used as reducing, capping, and stabilizing agents. These bioactive polyphenols have been extracted from various vegetation's leaves, stems, roots, flowers, fruits, fruit peels, seeds, gums, and even garbage [21].

The industries release poisonous dyes including methyl orange, malachite green, orange dye, and heavy metals like arsenic and chromium.

Due to their toxicity and cancer-causing properties, these organic and inorganic substances should not be present in an aquatic environment [4]. Many recent studies have indicated the potential of iron nanoparticles (NPs) for environmental remediation [22]. The iron-based nanoparticles are effective environmental cleanup agents, particularly in in situ methods, due to their adsorptive and reductive properties. They work well in degrading various organic and inorganic pollutants and are inexpensive and non-toxic. Moreover, they can be used in conjunction with other strategies including chemical oxidation and bioremediation, as well as the activation of chemical oxidants to boost their potency [23].

5.1. Environmental pollutant

Due to their potentially harmful impacts on the environment, toxic pollutants like dyes, antibiotics, heavy metals, and POPs have drawn the attention of several researchers [24]. The uncontrolled usage of various dye, heavy metals, and other pollutant in different industrial and home applications has caused the dangerous effect on living things [25]. For instance, arsenic is one of the most common industrial pollutants which are posing serious ecosystem threats. Both anthropogenic and natural sources contribute to the environmental arsenic pollution [26]. A significant number of dye effluents are reported to be released into water bodies by industries like cosmetic, paint, leather, and textile. The buildup of these dyes on the surface of water prevents the sunlight from penetrating for eutrophication. It also raises chemical oxygen demand, which eventually has an impact on the aquatic ecology [27].

5.1.1. Degradation of dyes

A dye is an organic colorant that contains a structure that produces color and has an affinity for the substrate to which it is applied. To impart various color tones to fabrics and other supporting materials used in the textile, food, and other industries, dyes can be permanently fastened to them. Chloropytum comosum leaf extract was used to create iron nanoparticles, and the resulting particles were used to decolorize methyl orange and fight germs. The only reduction and stabilizing agent used in this procedure is water dispersion of chloropytum comosum leaf extract, which is added to the iron salt precursor. Methyl orange was used as a model contamination to examine the dye removal activity of H2O2-catalyzed iron nanoparticles toward degradation of organic contaminants. The findings of this study revealed that the highest efficiency of methyl orange degradation (77%) was occurred after 6 hours [6]. Iron oxide nanoparticles were created by using papaya plant (Carica papaya) leaf extract. In the sunlight presence, the synthesized iron oxide nanoparticle effectively degraded yellow RR dye, removing 77% of the dye in 6 hours for a dosage of 0.8 mg/L [28]. In a different investigation, green-synthesized iron oxide NPs was shown to have exceptional performance for the methyl orange degradation in the presence of the H_2O_2 aqueous solution. The findings demonstrated that the IONPs majority have spherical shapes with sizes between 4.6-30.6 nm. Therefore, the ecologically safe and environmentally friendly technique for making IONPs by plant-mediated synthesis is one that can be employed for a variety of purposes, such as a heterogeneous Fenton-like catalyst for the degradation of azo dyes. [29]. In this regard, [30] reported the MGO-laccase displayed a sufficient magnetic response and acceptable reusability at the ideal pH and temperature settings (pH 3.0 and 35 °C). After ten uses, the MGO-activity laccase's was restored to 59.8%. The elimination of crystal violet (CV), malachite green (MG), and brilliant green (BG) in an aqueous solution reached 94.7%, 95.6%, and 91.4% when MGO-laccase was next used in the de-colorization of dye solutions. According to the experimental findings, MGO-laccase nanoparticles significantly increased the processing efficiency and broadened the use of enzymes in industry. In addition, FeONPs were created by utilizing Piper betle extract under natural circumstances. Potentially, the phenolic chemicals in the Piper betle function as both capping and reducing agents. The created FeONPs efficiently accelerated the degradation of MO and MG dyes [31]. By using OT-FeNP to degrade malachite green (MG), the kinetics was fit well to the pseudo-first-order reaction, eliminating 75.5% of MG (50 mg/L).

This suggested that OT-FeNP could be used as a green nanomaterial for environmental remediation [32]. Photo catalytic dye degradation by irradiation generates electron-hole pairs, which are then reacted on the nanoparticle surface, resulting in the formation of hydroxyl radicals. These radicals have the ability to serve as oxidizing agents, degrading toxic pigments. When exposed to visible or the UV light, nanoparticles operate as photo catalysts, causing a redox reaction that results in the electrons creation in the conduction band and H^+ in the valence band, leading in the generation of electron hole pairs. The electron-hole couples trigger a sequence of redox events on the surface of the photo catalyst. At the same time, H+ interacts with water, producing OH free radicals upon oxidation. The conduction band electrons combine with oxygen on the nanoparticles surface to form intermediates such as superoxide radical, per hydroxyl radical, and H_2O_2, and finally •OH in the reduction process, which occurs on the nanoparticles surface as photocatalyst. This radical further helps in the degradation of harmful dyes [27, 33].

5.1.2. Removal of heavy metals

Heavy metals can be found in the environment naturally or as a result of human activity. The anthropogenic sources of heavy metals in the aquatic environment include mining, agricultural practices, and municipal sewage sludge, among others. The natural sources of heavy metals in the aquatic environment include erosion, rock weathering, and volcanic eruption [34]. Settings constitute a severe hazard. As a result, it is crucial to control the level of heavy metals in wastewaters before they are released into the environment to be fast, one-stage, 100% eco-friendly production of iron oxide nanoparticles (Fe_3O_4NPs). It was demonstrated that the nanoparticles biosynthesis by using plant extracts appears to be effective and can be utilized to remove hazardous metals like lead and cadmium by decreasing the iron chloride solution with Ramalina Sinensis extract containing sulfate polysaccharide. The Langmuir adsorption model for lead was followed by the Freundlich isotherm model for cadmium (R^2=0.999), according to the thermodynamic research and adsorption inquiry, and exothermic and spontaneous removal is the adsorption process. A second-order kinetic model with a suitable correlation coefficient of 0.99 was used to fit the results from kinetic studies of the removal of lead and cadmium from aqueous solutions. For an initial concentration of 50 mg/l and a pH in the range of 4-5, the removal efficiency of lead and cadmium by magnetic nanoparticles of iron oxide was 82% and 77%, respectively [35]. In another study, the EDTA-modified Fe_3O_4/SC nanoparticles and magnetic nanoparticles with sawdust carbon were created. By utilizing batch mode studies, Cd (II) was adsorbed from an aqueous solution by using these materials. The maximum adsorption capacity of EDTA@Fe_3O_4/SC ncs according to Langmuir is 63.3 mg/g, which is higher than the 51 mg/g of Fe_3O_4/SC ncs. The Cd (II) adsorption is best modeled by the pseudo-second-order model. Studies on the thermodynamics of Cd (II) adsorption revealed that it is possible, spontaneous, and endothermic. Divalent cations (Ca^{2+} and Mg^{2+}) that coexist may have an impact on Cd (II) adsorption. The studies on desorption and recycling revealed that EDTA@Fe_3O_4/SC ncs was a cost-effective and long-lasting adsorbent for removing metal from an aqueous solution. In comparison to unmodified Fe3O4/SC ncs, the potential for Cd (II) adsorption is increased after the EDTA treatment.

The findings make it clear that the carboxyl groups on the surface of EDTA@Fe_3O_4/SC ncs play a role in Cd (II) adsorption. The electronic attraction and chemical adsorption were both components of the adsorption mechanism. This study suggests that the biogenic green synthesis method can be used to create EDTA@Fe_3O_4/SC ncs for the removal of heavy metals from wastewater [36]. The findings make it clear that the carboxyl groups on the EDTA@Fe_3O_4/SC ncs' surface play a role in the Cd (II) adsorption. The electronic attraction and chemical adsorption were both components of the adsorption mechanism. This study suggests that the biogenic green synthesis method can be used to create EDTA@Fe_3O_4/SC ncs for the removal of heavy metals from wastewater [37]. Another study also stated that the iron nanoparticles were created by using blueberry leaf extracts, which had less agglomeration than nZVI and did not require the use of dispersants because of the capping created during the synthetic process. Due to a decrease in the active areas operating from materials of the organic remnants that remain adsorbed after conflation, research on (V) junking has shown that BB-Fe NPs have a decreased likelihood of arsenate junking. However, by using these kinds of leftovers enables the production of inexpensive and environmentally benign nanomaterials [38]. The results showed that the biosynthesized Fe_3O_4-NPs alginate beads via *Padina pavonica* plant had a high capacity for bioremoving Pb (91%), while that of S. acinarium had a capacity of (78%) after 75 minutes. The biosynthesized Fe_3O_4-NPs alginate beads via P. pavonica had a high capacity for bioremoving Pb (91%), while that of S. acinarium had a capacity of (78%) after 75 min [39].

5.1.3. Wastewater treatment

Wastewater comes from different sources, including sewage, industrial and commercial waste, agricultural waste, and others. These wastes can be identified by their physical characteristics, chemical makeup, and the abundance of microorganisms. For instance, the iron oxide nanoparticles were created by using Cynometra ramiflora leaf extract and used in a Fenton-like catalytic process with hydrogen peroxide to degrade Rhodamine B, a carcinogen. When 1.11 mM nanoparticles were used with 2% H_2O_2, the degradation was discovered to be at its best within 15 minutes. A procedure like this was discovered to create the least amount of sludge, making it superior to other Fenton-catalyzed processes [29, 40]. A study by [41] synthesized by using Persicaria bistorta root extract as a reducing agent, Fe3O4 MNPs. Comparing the author's method to the current chemical methods, the former is both cost-effective and environmentally beneficial. Furthermore, the created magnetite nanoparticles are presented as a powerful new adsorbent in the effluent treatment from rose water distillation. Eucalyptus leaf extract was also used in the synthesis of the iron polyphenols complex. They have investigated the synthetic particle's ability to adsorb and flocculate by using Acid Black. The greatest adsorption-flocculation capacity per gram of iron polyphenols complex was achieved at 1.6 g. They have also mentioned the possibility of using this substance for groundwater cleanup and water filtration. The produced iron nanoparticles were utilized to remediate swine effluent, and the author further reported on iron nanoparticles by using eucalyptus leaf extracts. The outcomes showed that the synthetic iron nanoparticles successfully eliminated 84.5% of COD and 71.1% of total N [4]. Likewise, the iron nanoparticles where synthesized by using Eichhornia crassipes, Lantana Camara, and Mimosa pudica. The author's result showed that the synthesized FeNPs are efficient for the simultaneous removal of nitrate and phosphate. Moreover, its stability provides an alternative for eutrophic wastewater treatment. Overall, the synthesis method is simple, feasible, and efficient as it can be performed at room temperature with limited resources [42]. FeNPs were synthesized by using various leaf extracts (MC-FeNPs, AI-FeNPs, MI-FeNPs, and MK-FeNPs). An experimental study with AI-FeNPs showed 98.1%, 84.3%, and 82.4% removal of total phosphates, ammonia nitrogen, and COD accounted and further it was proved to be higher, as compared with other FeNPs. Moreover, it is pragmatic that pH during the entire study was within the range of 6.5 to eight for AI-FeNPs and no buffer agent is added. The study proved that the utilized leaf extracts are amicable for the treatment of domestic wastewater as an alternate option. Also, the study persuasively illustrated the environmentally friendly practice which may be handled by biodegradable matter efficiently and bearing tremendous potential for in situ treatment process for simultaneous removal [43]. In addition, the iron-based nanoparticles synthesized by using eucalyptus leaf extract with and without the addition of β-cyclodextrin. The authors reported that β-cyclodextrin has improved the dimensions and reactivity of the nanoparticle, the synthesized nanoparticle is used to remove azo dyes from wastewater. The authors have achieved a removal efficiency of 86% with 215.1 mg/g removal capacity [44].

5.1.4. Pollutant degradation

Because nanoparticles can aggregate, this decreases their efficiency for catalytic and adsorptive activities. Nanoparticles were immobilized within polymeric, zeolitic, and silica-based substrates to get around this restriction. A study by [21] synthesized nanoparticles by using a green synthesis process, Fe and bimetallic Fe/Pd nanoparticles are added to a polyvinylidene fluoride (PVDF) membrane as support. Polyacrylic acid (PAA) was used to modify PVDF membranes through a polymerization reaction, while tea extract was used as a reducer to create Fe and Fe/Pd nanoparticles. The average particle diameter of the nanoparticles incorporated in the PVDF/PAA membrane was determined to be 20–30 nm. The degradation of trichloroethylene, a harmful organic pollutant, was studied by using the produced nanoparticle impregnated membrane (TCE). More nanoparticle incorporation into the membrane was shown to increase the catalytic reactivity of the membrane in dechlorinating the TCE molecule. Likewise, rather than just using Fe nanoparticles, bimetallic Fe/Pd inclusion was mentioned to improve the catalytic process. In a different publication, ferrate (VI)-based nanoparticle was used in soil remediation and ground water purification. Without causing any environmental issues, ferrate has considerable promise for a various environmental applications. The study by the author gives in-depth information on the recent developments in the usage of ($FeVIO_4^{2-}$) as a green substance to be employed in long-term sustainable treatment processes, particularly for soil and water remediation.

As oxidants, coagulants, and disinfectants for the removal of a wide variety of chemical and biological species from water/wastewater samples, ferrates ($FeVIO_4^{2-}$) and their associated physicochemical features were also studied by the author. The performance of Ferrate (VI eco-sustainable) in water filtration is summarized as follows. In soil and wastewater media, ferrate nanoparticles demonstrated the improved organic micro-pollutant removal [45]. In relevance to the aforementioned points, the green synthesis was used to create nano zero-valent irons (NZVI) from nettle (NNZVI) and thyme (TNZVI) leaf extracts. The CEX removal capacity of each of these, according to the author, is remarkably great. The findings demonstrated that NNZVI and TNZVI had monolayer adsorption capabilities for CEX of 1667 mg/g and 1428 mg/g, respectively. These numbers are comparable to the best activated carbons on the market today [46]. Furthermore, the green technique was used to create the hybrid Fe/Ni-rGO material. The material was thoroughly characterized by using a variety of cutting-edge techniques, which showed that GO was successfully reduced to rGO and that Fe and Ni nanoparticles were distributed over the rGO surface. In a mixed contaminant system, the efficiency of removing Pb (II) and RIF was slightly decreased, falling to 81.9% and 94.3% for Pb (II) and RIF, respectively. Fe/Ni-ability rGO's to simultaneously remove Pb (II) and RIF involved the surface adsorption on rGO and the catalytic reduction of RIF by Fe/Ni bimetal nanoparticles coated with the rGO's surface. Furthermore, during the removal process, these two contaminations engage in competitive adsorption. Fe/Ni-rGO indicated the good performance and reusability in wastewater containing Pb (II) and RIF pollutants. Due to the great efficiency found here, hybrids Fe/Ni-rGO are anticipated to be extensively used in the future for catalysis and the pollution treatment [47]. The majority of scientists have chosen by using plant extracts to create iron-based nanoparticles for the removal of colors and other contaminants like heavy metals [48], nitrate [49], and organic environmental pollutant [50]. It may be due to it is cost-effective, and environmentally-pleasant synthesis method.

6. Conclusion and Future Perspective

A developing discipline called "green synthesis" aims to produce nanoparticles safely, effectively, and environmentally benign. Green synthesis, in contrast to the other synthesis techniques, aims to reduce the secondary effects by utilizing green reagents or by using manufacturing practices that use less energy and natural resources.

The recent studies on the environmentally friendly production of nanoparticles for wastewater treatment were covered in this review. It has emphasized the numerous green nanoparticles that have been created. Having the ability to regulate particle size and morphology is one of the primary difficulties in the NPs synthesis for environmental remediation. It was discovered that factors affecting green synthesis processes, such as pH, temperature, and reaction time had an impact on these properties.

The performance of green NPs and the mechanisms for contaminant removal were described, demonstrating how green NPs may aid in dye degradation and the removal of contaminants from water. The following significant elements were covered: (i) degradation mechanisms, (ii) heavy metal adsorption, and (iii) pollutant degradation.

Future study directions were identified, including large-scale assembly, the possible impact of greener NPs on plants, advancements in green NP morphology, and regeneration of the iron-based nanomaterials after adsorption.

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