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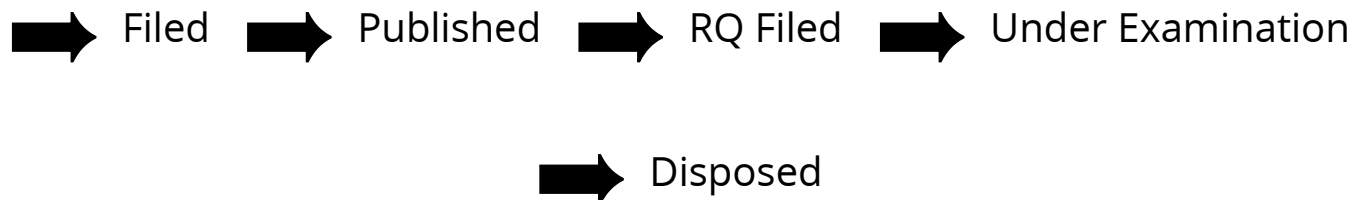
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(57) Abstract:

The present invention discloses a sustainable photocatalytic system for the effective degradation of black dye in industrial wastewater using green synthesized spinel ferrite nanoparticles. The nanoparticles are produced through a plant-mediated synthesis method employing natural phytochemicals as reducing and stabilizing agents, thereby eliminating hazardous chemicals and supporting eco-friendly fabrication. The synthesized nanomaterials exhibit a spinel crystal structure, high surface area, visible light responsiveness, and magnetic properties that allow easy recovery after treatment. Under solar or visible light irradiation, the nanoparticles generate reactive oxygen species that oxidize and mineralize complex dye molecules into non-toxic products such as carbon dioxide and water. The system reduces color intensity and chemical oxygen demand while minimizing sludge generation. Magnetic recoverability ensures catalyst reusability and operational cost reduction. The invention provides an environmentally benign, energy-efficient, and scalable approach for advanced wastewater remediation and sustainable water management.

FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

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The Patent Rules, 2003

COMPLETE SPECIFICATION

(See section 10 and rule 13)

TITLE OF THE INVENTION

**“Photodegradation of Black Dye by Green Synthesis of Spinel Ferrite
Nanoparticles”**

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The following specification particularly describes the nature of the invention and the manner in which it is performed:

Field of the invention:

The present invention falls within the field of nanotechnology and environmental remediation, particularly relating to the green synthesis and application of spinel ferrite nanoparticles for wastewater treatment. More specifically, the invention pertains to the development of eco-friendly, plant-mediated synthesized spinel ferrite nanomaterials for the photocatalytic degradation of industrial black dyes in contaminated water. The proposed system integrates principles of materials science, environmental engineering, and sustainable chemistry to address dye pollution in textile and related industries. It involves the preparation of spinel ferrite nanoparticles using green synthesis methods that eliminate toxic chemical reducing agents. The invention further relates to photocatalytic processes activated under visible or solar light for efficient degradation of persistent organic dye pollutants. Additionally, it encompasses nanostructured magnetic catalysts that enable easy separation and recyclability after treatment. The field also includes advanced oxidation processes facilitated by ferrite-based semiconductor materials. The invention contributes to wastewater purification technologies aimed at reducing environmental and public health hazards. Furthermore, it aligns with green chemistry approaches for sustainable nanomaterial fabrication. Overall, the proposed system resides at the intersection of nanomaterials engineering, photocatalysis, and eco-friendly wastewater treatment technologies.

Background of the invention:

Industrialization and rapid urban development have significantly increased the discharge of synthetic dyes into aquatic environments, creating serious ecological and public health concerns. Among various industrial pollutants, synthetic black dyes are widely used in textile, leather, paper, plastic, cosmetic, and printing industries due to their intense coloration, stability, and resistance to fading. However, these same properties that make black dyes commercially valuable also make them highly persistent in natural water bodies. Once discharged into wastewater streams without adequate treatment, black dye molecules reduce light penetration in water, thereby disturbing photosynthetic activity in aquatic ecosystems. This reduction in light availability disrupts dissolved oxygen balance and negatively affects aquatic flora and fauna. Moreover, many black dyes contain complex aromatic structures, azo linkages,

and auxiliary chemicals that exhibit carcinogenic, mutagenic, or toxic effects on living organisms.

Conventional wastewater treatment methods such as coagulation, flocculation, adsorption, membrane filtration, and biological treatment have been employed to remove dyes from effluents. Although these techniques can partially reduce dye concentration, they often suffer from significant limitations including incomplete degradation, high operational cost, sludge generation, secondary pollution, and limited effectiveness against chemically stable dye molecules. Biological treatments, for example, are less efficient because many synthetic dyes are non-biodegradable due to their complex molecular structures. Physical adsorption methods transfer pollutants from one phase to another without completely mineralizing them, leading to further disposal challenges. Chemical oxidation methods can be effective but frequently require harsh reagents, high energy input, and generate undesirable by-products.

In recent decades, advanced oxidation processes have emerged as promising alternatives for the degradation of persistent organic pollutants. Among these, photocatalysis has gained particular attention due to its ability to completely mineralize organic contaminants into harmless end products such as carbon dioxide and water under light irradiation. Photocatalytic processes utilize semiconductor materials that absorb light energy to generate electron-hole pairs, which subsequently produce reactive oxygen species capable of oxidizing complex dye molecules. The effectiveness of photocatalysis depends largely on the properties of the catalyst material, including its band gap, surface area, stability, and reusability.

Nanotechnology has introduced significant advancements in photocatalysis through the development of nanoscale materials with enhanced surface-to-volume ratios and improved catalytic efficiency. Nanoparticles exhibit unique physicochemical properties compared to their bulk counterparts, including higher reactivity and tunable electronic structures. Among various nanomaterials investigated for photocatalytic applications, spinel ferrite nanoparticles have attracted considerable interest. Spinel ferrites, typically represented by the general formula MFe_2O_4 where M may be metals such as nickel, cobalt, zinc, or manganese, possess remarkable magnetic, electrical, and catalytic properties. Their narrow band gap and strong absorption in the visible light region make them suitable candidates for solar-driven photocatalytic processes.

Additionally, spinel ferrite nanoparticles offer the distinct advantage of magnetic separability. After completion of the photocatalytic reaction, the nanoparticles can be easily recovered from treated water using an external magnetic field, minimizing material loss and enabling repeated reuse. This magnetic recoverability addresses one of the primary challenges associated with nanoparticle-based treatment systems, namely the difficulty of post-treatment separation.

Despite the promising properties of spinel ferrite nanoparticles, conventional synthesis methods such as sol-gel processing, hydrothermal synthesis, co-precipitation, and combustion techniques often require high temperatures, toxic solvents, hazardous reducing agents, and energy-intensive procedures. These chemical synthesis routes may generate secondary pollutants and raise environmental and safety concerns. Furthermore, the use of toxic chemicals contradicts the objective of developing sustainable environmental remediation technologies.

To overcome these drawbacks, green synthesis approaches have been developed as environmentally friendly alternatives. Green synthesis utilizes natural biological resources such as plant extracts, microorganisms, and biodegradable polymers as reducing, stabilizing, and capping agents in nanoparticle fabrication. Plant-mediated synthesis, in particular, has gained attention due to its simplicity, cost-effectiveness, scalability, and eco-friendly nature. Phytochemicals present in plant extracts, including flavonoids, alkaloids, phenolics, and proteins, act as natural reducing and stabilizing agents, eliminating the need for harmful chemicals.

The integration of green synthesis techniques with spinel ferrite nanoparticle fabrication offers a sustainable pathway for producing photocatalysts suitable for wastewater treatment. By combining eco-friendly synthesis with advanced photocatalytic performance, such systems aim to minimize environmental impact during both production and application stages. Moreover, green synthesized nanoparticles often exhibit enhanced surface functionality due to phytochemical capping, which may further improve photocatalytic efficiency.

The increasing demand for sustainable and efficient dye removal technologies highlights the need for innovative systems capable of addressing both environmental contamination and resource conservation. The proposed invention emerges from the recognition that an ideal wastewater treatment solution should not only degrade

pollutants effectively but also be economically viable, environmentally benign, and easily recoverable. The utilization of green synthesized spinel ferrite nanoparticles aligns with global efforts to promote green chemistry principles, reduce hazardous chemical usage, and encourage renewable resource-based technologies.

Furthermore, the application of visible or solar light as an energy source for photocatalytic degradation reduces dependency on artificial ultraviolet light systems, thereby lowering operational costs and energy consumption. This solar-driven approach is particularly advantageous in regions with abundant sunlight, making the technology accessible and practical for large-scale deployment. The synergy between magnetic recoverability, visible-light responsiveness, and eco-friendly synthesis positions spinel ferrite nanoparticles as promising materials for next-generation wastewater treatment systems.

Environmental regulations worldwide are becoming increasingly stringent regarding dye effluent discharge standards. Industries are therefore compelled to adopt advanced treatment technologies that ensure complete pollutant degradation rather than partial removal. The proposed invention addresses this regulatory and environmental challenge by providing a sustainable photocatalytic system capable of degrading black dyes into less harmful or non-toxic components. The system contributes to the reduction of chemical oxygen demand and total organic carbon levels in treated water, thereby improving water quality and facilitating safe discharge or reuse.

In summary, the background of the proposed invention is rooted in the urgent need to mitigate dye pollution through innovative, sustainable, and efficient treatment strategies. Limitations of conventional methods, environmental concerns associated with chemical synthesis routes, and the growing emphasis on green chemistry have collectively driven the exploration of plant-mediated synthesis of spinel ferrite nanoparticles. By leveraging the unique magnetic and photocatalytic properties of these nanomaterials, the proposed system aims to provide an effective solution for the photodegradation of black dyes in industrial wastewater while ensuring environmental compatibility, economic feasibility, and operational sustainability.

In addition to environmental contamination, the persistence of black dyes in aquatic systems poses significant socio-economic challenges. Contaminated water sources

affect agricultural productivity when used for irrigation, as dye residues may alter soil chemistry and inhibit plant growth. Livestock and wildlife consuming polluted water may accumulate toxic compounds in their tissues, leading to bioaccumulation and biomagnification within the food chain. Human exposure to dye-contaminated water, whether through direct contact or consumption, has been associated with skin irritation, respiratory problems, and long-term health risks due to the presence of aromatic amines and other hazardous degradation intermediates. These concerns emphasize the importance of developing treatment technologies capable of complete mineralization rather than simple decolorization.

Another critical limitation of existing treatment systems lies in their inability to function efficiently under varying pH, temperature, and pollutant concentration conditions commonly observed in industrial effluents. Textile wastewater, for instance, often contains high salt concentrations, surfactants, auxiliary chemicals, and fluctuating pH levels that can interfere with treatment efficiency. Therefore, an effective photocatalytic material must demonstrate chemical stability, structural integrity, and catalytic performance under diverse environmental conditions. Spinel ferrite nanoparticles are particularly advantageous in this regard due to their robust crystal structure, thermal stability, and resistance to chemical corrosion.

The nanoscale dimension of ferrite particles provides a significantly increased active surface area, allowing more dye molecules to interact with catalytic sites simultaneously. Enhanced adsorption of dye molecules on the catalyst surface facilitates rapid generation of reactive oxygen species such as hydroxyl radicals and superoxide anions under light irradiation. These highly reactive species attack the chromophoric groups of black dye molecules, breaking azo bonds and aromatic rings into smaller, less complex fragments. Continuous oxidation ultimately converts these fragments into carbon dioxide, water, and inorganic ions, achieving near-complete mineralization.

Despite these advantages, challenges such as electron–hole recombination within semiconductor materials can reduce photocatalytic efficiency. The recombination process dissipates absorbed light energy as heat instead of generating reactive species. Spinel ferrite nanoparticles help mitigate this limitation due to their favorable band structure and electron transfer properties. Furthermore, the presence of

transition metal ions within the ferrite lattice can enhance charge separation efficiency and promote interfacial redox reactions. Optimization of particle size, morphology, and surface chemistry through green synthesis further contributes to improved catalytic performance.

Green synthesis methods not only reduce environmental hazards during production but also influence the structural characteristics of the nanoparticles. Phytochemicals present in plant extracts can control nucleation and growth rates during nanoparticle formation, resulting in uniform particle size distribution and reduced agglomeration. Surface functional groups derived from plant biomolecules may improve dispersibility in aqueous media, thereby increasing contact between the catalyst and dye molecules. This enhanced interaction can lead to higher degradation rates compared to conventionally synthesized counterparts.

Scalability is another important factor influencing the adoption of nanoparticle-based treatment technologies. Traditional chemical synthesis techniques often involve complex procedures, expensive equipment, and high energy consumption, limiting large-scale production. In contrast, plant-mediated synthesis can be performed under ambient conditions using readily available biological resources. This simplicity reduces manufacturing costs and makes the technology accessible for industrial and municipal wastewater treatment applications. Additionally, the use of renewable plant materials aligns with circular economy principles and sustainable resource utilization.

Magnetic recoverability remains one of the most distinguishing features of spinel ferrite nanoparticles in wastewater treatment. After photocatalytic degradation, the nanoparticles can be separated quickly using an external magnet, eliminating the need for filtration or centrifugation. This property not only reduces operational complexity but also prevents secondary nanoparticle contamination in treated water. Recovered nanoparticles can be washed and reused in subsequent treatment cycles, enhancing cost-effectiveness and long-term sustainability. Reusability studies have demonstrated that ferrite-based photocatalysts can retain significant catalytic activity over multiple cycles, highlighting their durability.

The global push toward sustainable development goals has intensified research efforts aimed at clean water technologies. Governments and regulatory bodies increasingly encourage the adoption of environmentally friendly treatment methods that minimize

chemical usage and energy consumption. Solar-driven photocatalysis using green synthesized magnetic nanoparticles fits within this framework by utilizing renewable energy and biodegradable resources. Such systems reduce carbon footprint compared to conventional high-energy treatment processes.

Another aspect contributing to the relevance of the proposed invention is the integration potential with existing wastewater treatment infrastructure. Spinel ferrite nanoparticle-based photocatalytic units can be incorporated as tertiary treatment stages following primary sedimentation and biological processes. This integration enhances overall treatment efficiency by targeting residual dye molecules that escape conventional systems. The modular nature of photocatalytic reactors allows adaptation to different industrial scales, from small textile workshops to large manufacturing facilities.

Furthermore, ongoing advancements in nanomaterial characterization techniques have enabled better understanding of structure–property relationships in spinel ferrites. Techniques such as X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and UV–visible spectroscopy allow precise analysis of crystal phase, morphology, particle size, and optical properties. These insights facilitate optimization of synthesis parameters to achieve superior photocatalytic performance. Continuous improvement in nanoparticle design strengthens the feasibility of practical implementation.

The proposed invention is also motivated by the need to reduce sludge generation associated with traditional dye removal methods. Sludge disposal poses environmental risks and incurs additional costs. Photocatalytic degradation, by contrast, aims to destroy pollutant molecules rather than transfer them into another phase. This fundamental difference reduces solid waste generation and contributes to cleaner treatment operations.

Climate change and water scarcity further amplify the importance of efficient wastewater reuse technologies. Treated industrial effluents can be recycled for non-potable applications such as irrigation, cooling, and cleaning if pollutant levels are sufficiently reduced. By ensuring effective degradation of persistent black dyes, the proposed photocatalytic system supports water conservation strategies and reduces pressure on freshwater resources.

In addition, the interdisciplinary nature of the invention bridges materials science, environmental chemistry, nanotechnology, and process engineering. Collaboration among these fields fosters innovation and accelerates the development of high-performance, eco-friendly treatment systems. The convergence of green synthesis and magnetic photocatalysis represents a progressive step toward sustainable nanotechnology applications.

Overall, the continuing environmental challenges associated with synthetic dye pollution, combined with the limitations of conventional treatment methods, underscore the necessity for improved remediation technologies. Green synthesized spinel ferrite nanoparticles provide a promising pathway to address these concerns through efficient photodegradation, magnetic recoverability, cost-effectiveness, and environmental compatibility. The proposed invention builds upon these advancements to offer a comprehensive solution aimed at safeguarding aquatic ecosystems, protecting public health, and promoting sustainable industrial practices.

Summary of the invention:

The proposed invention relates to an eco-friendly and efficient system for the photodegradation of black dye present in industrial wastewater using green synthesized spinel ferrite nanoparticles. The invention employs plant-mediated synthesis methods to prepare spinel ferrite nanomaterials without the use of toxic chemicals or hazardous reducing agents, thereby ensuring an environmentally sustainable production process. The synthesized nanoparticles possess a spinel crystal structure with enhanced surface area, visible light responsiveness, and magnetic properties that make them highly suitable for photocatalytic applications. Upon exposure to solar or visible light irradiation, the nanoparticles generate reactive oxygen species capable of breaking down complex black dye molecules into simpler, non-toxic end products such as carbon dioxide and water.

A key feature of the proposed system is the magnetic recoverability of the spinel ferrite nanoparticles, allowing easy separation from treated water using an external magnetic field. This characteristic enhances reusability, reduces operational costs, and prevents secondary nanoparticle contamination. The invention addresses the limitations of conventional dye removal techniques by achieving effective mineralization rather than mere decolorization or phase transfer of pollutants. It offers improved catalytic

efficiency, stability under varying wastewater conditions, and reduced sludge formation. Overall, the proposed invention provides a sustainable, cost-effective, and scalable solution for industrial wastewater treatment, contributing to environmental protection, water resource conservation, and advancement in green nanotechnology-based remediation systems.

Brief description of the proposed invention:

The proposed invention describes an environmentally sustainable and highly efficient system for the photodegradation of black dye present in industrial wastewater through the application of green synthesized spinel ferrite nanoparticles. The invention integrates principles of green chemistry, nanotechnology, and photocatalytic environmental remediation to provide an advanced treatment solution capable of addressing the persistent problem of dye contamination in water bodies. Industrial effluents, particularly from textile, leather, printing, and dye-manufacturing sectors, often contain high concentrations of black dyes characterized by complex aromatic molecular structures and strong chemical stability. These dyes are resistant to natural degradation processes and conventional wastewater treatment methods, thereby necessitating the development of innovative degradation technologies capable of complete mineralization.

The invention utilizes plant-mediated synthesis techniques for the preparation of spinel ferrite nanoparticles, eliminating the need for toxic chemical reducing agents, stabilizers, or high-energy processing conditions. In this approach, plant extracts rich in bioactive compounds such as flavonoids, phenolics, alkaloids, and proteins act as natural reducing and capping agents during nanoparticle formation. This green synthesis route not only minimizes environmental hazards during production but also enhances the surface functionality and dispersion stability of the nanoparticles. The process is cost-effective, scalable, and compatible with sustainable manufacturing practices.

The synthesized spinel ferrite nanoparticles possess a well-defined crystalline structure typically represented by the formula MFe_2O_4 , where M denotes a divalent metal ion. The nanoscale dimension of these particles provides a high surface-to-volume ratio, significantly increasing the number of active catalytic sites available for interaction with dye molecules. The optical properties of the spinel ferrite nanoparticles

enable them to absorb visible or solar light, making them suitable for photocatalytic reactions under natural sunlight conditions. Upon irradiation, the nanoparticles generate electron-hole pairs that initiate redox reactions at the catalyst surface. These reactions produce highly reactive oxygen species such as hydroxyl radicals and superoxide anions, which attack and break down the chromophoric structures of black dye molecules.

Through successive oxidation steps, the complex dye compounds are degraded into smaller, less harmful intermediates and ultimately mineralized into carbon dioxide, water, and inorganic ions. This complete mineralization distinguishes the proposed invention from conventional treatment methods that merely transfer pollutants from one phase to another without destroying them. The photocatalytic process reduces chemical oxygen demand, color intensity, and overall organic pollutant load in the treated effluent, thereby improving water quality and enabling safer discharge or reuse.

A significant advantage of the invention lies in the magnetic properties of spinel ferrite nanoparticles. After completion of the photocatalytic degradation process, the nanoparticles can be easily separated from the treated water using an external magnetic field. This magnetic recoverability simplifies the post-treatment separation process, eliminates the need for complex filtration systems, and enhances the economic feasibility of the system. The recovered nanoparticles retain substantial catalytic activity and can be reused for multiple treatment cycles, thereby reducing material consumption and operational costs.

The invention further demonstrates high stability under varying environmental conditions, including fluctuations in pH, temperature, and pollutant concentration commonly observed in industrial effluents. The robust spinel structure ensures chemical and thermal stability, while the surface functional groups introduced during green synthesis improve dispersion and prevent agglomeration. These characteristics collectively contribute to consistent photocatalytic performance over repeated usage cycles.

In addition to its operational efficiency, the proposed invention aligns with global environmental sustainability goals by promoting renewable resource utilization and reducing hazardous chemical usage. The reliance on plant-based extracts for

nanoparticle synthesis supports eco-friendly production practices and lowers the carbon footprint associated with catalyst manufacturing. The use of visible or solar light as the energy source further enhances sustainability by reducing dependence on artificial ultraviolet light systems and minimizing energy consumption.

The system can be implemented as a standalone treatment unit or integrated into existing wastewater treatment infrastructures as an advanced tertiary treatment stage. Its modular design allows adaptation for small-scale industrial operations as well as large-scale municipal treatment facilities. The simplicity of the synthesis process and the ease of catalyst recovery make the technology suitable for practical field applications.

Overall, the proposed invention provides a comprehensive and sustainable solution for the effective photodegradation of black dye pollutants in wastewater. By combining green synthesis methodologies with magnetic, visible-light-responsive spinel ferrite nanoparticles, the system offers high degradation efficiency, reusability, environmental compatibility, and cost-effectiveness. The invention contributes to the advancement of green nanotechnology-based water treatment strategies and addresses the urgent need for improved remediation technologies capable of protecting aquatic ecosystems and public health from dye-related pollution.

The proposed invention further encompasses optimization of synthesis parameters to control particle size, morphology, crystallinity, and surface characteristics of the spinel ferrite nanoparticles in order to maximize photocatalytic efficiency. By adjusting factors such as precursor concentration, plant extract composition, reaction temperature, pH, and calcination conditions, nanoparticles with uniform size distribution and enhanced surface reactivity can be obtained. Smaller particle sizes contribute to increased surface area and shortened charge carrier diffusion paths, thereby reducing electron–hole recombination and improving generation of reactive oxygen species during light irradiation.

The invention also considers the influence of operational parameters during the photodegradation process, including catalyst dosage, initial dye concentration, irradiation time, light intensity, and solution pH. Optimization of these parameters ensures maximum degradation efficiency within a practical time frame while maintaining economic viability. The system is designed to perform effectively under

visible light or natural sunlight, eliminating the requirement for expensive ultraviolet light sources and thereby reducing energy consumption. This feature makes the technology particularly advantageous for deployment in regions with high solar availability, where sunlight can serve as a renewable and cost-free energy source.

In practical application, the photocatalytic reaction occurs when contaminated wastewater containing black dye is exposed to light in the presence of the green synthesized spinel ferrite nanoparticles. The dye molecules first adsorb onto the nanoparticle surface, facilitated by electrostatic interactions and surface functional groups derived from plant biomolecules. Upon illumination, the catalyst absorbs photons and generates excited electrons and corresponding holes. These charge carriers migrate to the nanoparticle surface, where they react with dissolved oxygen and water molecules to form reactive radicals. The radicals then attack the dye molecules, cleaving azo bonds, disrupting aromatic rings, and progressively oxidizing intermediate compounds.

The invention emphasizes durability and long-term stability of the catalyst under repeated usage. Magnetic separation enables easy retrieval of the nanoparticles after each treatment cycle, followed by washing and drying for reuse. Performance retention over multiple cycles demonstrates the robustness of the spinel ferrite structure and its resistance to photocorrosion. The reduction in catalyst loss during recovery enhances economic feasibility and minimizes environmental risks associated with nanoparticle release.

Another important aspect of the invention is its compatibility with continuous flow and batch reactor configurations. In batch systems, contaminated water is treated in a controlled reactor environment for a predetermined duration. In continuous systems, wastewater flows through a reactor chamber containing suspended or immobilized magnetic nanoparticles under constant light exposure. The magnetic property of the nanoparticles also allows potential immobilization on magnetic substrates, further simplifying separation and preventing particle aggregation.

The invention contributes to reduced sludge formation compared to conventional coagulation or precipitation-based dye removal techniques. Since the photocatalytic process aims to chemically degrade pollutants rather than transfer them into a solid

phase, secondary waste generation is minimized. This reduces disposal costs and environmental impact associated with sludge handling.

Additionally, the proposed system supports water reuse initiatives by producing treated effluent with significantly reduced color intensity, chemical oxygen demand, and organic pollutant levels. Such treated water may be reused for non-potable industrial processes, irrigation, or cleaning applications, thereby conserving freshwater resources and promoting sustainable water management practices.

The invention also offers flexibility in selecting different divalent metal ions within the spinel ferrite structure to tailor optical and magnetic properties according to specific treatment requirements. Variation in metal composition allows tuning of band gap energy and catalytic activity, enabling adaptation for degradation of different classes of dye pollutants beyond black dye. This versatility broadens the potential application scope of the technology across multiple industrial sectors.

Safety considerations are addressed through the use of biodegradable plant extracts and elimination of toxic chemical reagents during synthesis. The green production process reduces occupational hazards and environmental emissions associated with traditional nanoparticle fabrication techniques. Furthermore, magnetic recovery prevents nanoparticle accumulation in treated water, ensuring compliance with environmental safety standards.


Overall, the extended description of the proposed invention highlights its integrated design, combining sustainable synthesis, efficient photocatalytic degradation, magnetic recoverability, operational adaptability, and environmental compatibility. The system represents a practical advancement in wastewater treatment technology by offering a renewable energy-driven, reusable, and eco-friendly solution for the effective removal and mineralization of persistent black dye pollutants.

We Claim:

1. A photocatalytic system for degradation of black dye in wastewater comprising green synthesized spinel ferrite nanoparticles prepared using plant extract as a natural reducing and stabilizing agent, wherein the nanoparticles possess a nanoscale spinel crystal structure and are responsive to visible or solar light irradiation for effective dye degradation.
2. The photocatalytic system wherein the plant extract contains bioactive phytochemicals including flavonoids, phenolics, alkaloids, or proteins that facilitate reduction of metal precursors, control nanoparticle growth, and stabilize the formed spinel ferrite nanoparticles without the use of toxic chemical reagents.
3. The photocatalytic system wherein the spinel ferrite nanoparticles have a general formula MFe_2O_4 , where M is a divalent metal ion selected from nickel, cobalt, zinc, manganese, or combinations thereof, enabling enhanced visible light absorption and improved catalytic efficiency.
4. The photocatalytic system wherein, upon light irradiation, the nanoparticles generate reactive oxygen species including hydroxyl radicals and superoxide anions that oxidize and mineralize black dye molecules into environmentally benign end products.
5. The photocatalytic system wherein the nanoparticles exhibit intrinsic magnetic properties that enable rapid separation from treated wastewater using an external magnetic field, thereby facilitating catalyst recovery and reuse.
6. The photocatalytic system wherein the degradation process significantly reduces color intensity, organic pollutant concentration, and chemical oxygen demand in wastewater while minimizing secondary sludge formation.
7. The photocatalytic system wherein the nanoparticles possess high surface area, controlled morphology, and reduced electron–hole recombination rate to enhance photocatalytic performance and reaction efficiency under visible light.
8. The photocatalytic system configured for operation in batch or continuous flow reactors, allowing integration into existing wastewater treatment facilities and adaptability for small-scale and large-scale industrial applications.

9. The photocatalytic system capable of maintaining catalytic stability and degradation efficiency under varying pH, temperature, and dye concentration conditions commonly encountered in industrial effluents.
10. The photocatalytic system utilizing solar or visible light as an energy source, wherein the green synthesis approach and magnetic reusability collectively provide a sustainable, cost-effective, and environmentally compatible wastewater treatment solution.

Dated this 18th day of February 2026

Signature: 

Applicant(s)


Dr. Vrashali S Kalyani et. al.

ABSTRACT

Photodegradation of Black Dye by Green Synthesis of Spinel Ferrite Nanoparticles

The present invention discloses a sustainable photocatalytic system for the effective degradation of black dye in industrial wastewater using green synthesized spinel ferrite nanoparticles. The nanoparticles are produced through a plant-mediated synthesis method employing natural phytochemicals as reducing and stabilizing agents, thereby eliminating hazardous chemicals and supporting eco-friendly fabrication. The synthesized nanomaterials exhibit a spinel crystal structure, high surface area, visible light responsiveness, and magnetic properties that allow easy recovery after treatment. Under solar or visible light irradiation, the nanoparticles generate reactive oxygen species that oxidize and mineralize complex dye molecules into non-toxic products such as carbon dioxide and water. The system reduces color intensity and chemical oxygen demand while minimizing sludge generation. Magnetic recoverability ensures catalyst reusability and operational cost reduction. The invention provides an environmentally benign, energy-efficient, and scalable approach for advanced wastewater remediation and sustainable water management.

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