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Proficient Adsorption Investigations of Methylene Blue Dye Utilizing Incorporated Mg-Doped CuO Nanoparticles: An Inventive Methodology for Powerful Methylene Blue Dye Treatment

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Authors' contributions

This work was carried out in collaboration among all authors. Author MI supervised the study, revised the manuscript and did data analysis. Author MM wrote and edited the manuscript. Author AR wrote and reviewed the manuscript and managed the discussion. Author KM wrote, reviewed and edited the manuscript. Author FM wrote and reviewed the manuscript and collected the materials. Authors RI and TM wrote and reviewed the manuscript and did synthesis. Author MI wrote, reviewed the manuscript and did mathematical interpretation. Author MM wrote and reviewed the manuscript and did data analysis. All authors read and approved the final manuscript.

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ABSTRACT

The growing contamination of water sources worldwide necessitates urgent interventions to ensure access to clean drinking water. Among the diverse pollutants, the discharge of dyes into water bodies presents a formidable environmental concern. Traditional wastewater treatment methods often fall short in addressing the persistence and toxicity of these contaminants, emphasizing the need for innovative approaches. In this study, we synthesized Mg-doped CuO nanoparticles using a co-precipitation method and characterized their chemical properties. The nanoparticles exhibited exceptional adsorption capabilities for various dye compounds, holding significant potential for wastewater remediation. Specifically, we investigated the removal of synthetic dyes using these metal-doped nanoparticles. Optimal parameters for maximal dye removal were determined through comprehensive experimentation, including adsorbent dosage, initial dye concentration, contact time, and temperature. Our results indicated that basic dye (Methylene Blue) demonstrated maximal adsorption at pH 5, with Mg-doped CuO nanoparticles exhibiting a superior adsorption capacity of 42.15 mg/g under optimized conditions (pH 5, 0.1 g/50 mL dosage, 120 minutes contact time, and 200 ppm dye concentration). Overall, our findings highlight the potential of Mg-doped CuO nanoparticles as an innovative and efficient solution for dye removal in wastewater treatment, offering a promising avenue for mitigating water pollution challenges.

Keywords: Nanotechnology; Mg doped CuO nanoparticles; methylene blue dye; co-precipitation method and wastewater treatment.

1. INTRODUCTION

Water, a basic requirement for human survival, is critical in maintaining life and promoting well-being [1]. Its importance goes beyond fundamental necessities, as it is a valuable resource in a variety of industries, including electronics, pharmaceuticals, and food production [2]. However, the availability of clean water is under threat from a number of factors, including protracted droughts, population expansion, strict regulations, and conflicting needs [3].

Nanotechnology, with its ability to control materials at the molecular and atomic levels, shows great promise for tackling water-related issues [4]. Water treatment stands out as a key area where nanotechnology has shown great promise [5]. Nanostructures, with their small size, wide surface area, and simplicity of functionalization, provide unparalleled prospects for developing more efficient catalysts and redox-active media for wastewater treatment [6].

Nanoparticles may successfully remove a variety of contaminants from wastewater, including heavy metals, organic solvents, and biological poisons [7]. Among these toxins, dyes from industries such as textile manufacture pose a substantial risk to water quality. The vivid wastewater streams produced by textile dying operations significantly contribute to water pollution, with more than 15% of dyes ending up in wastewater [8].

Textile effluents including dyes and other chemicals have distinct properties such as excessive salinity, turbidity, and color density, making them difficult to handle [9]. Furthermore, organic dyes employed in businesses can be very hazardous and carcinogenic, endangering aquatic life and human health [10].

In response to these issues, the adsorption process has evolved as a low-cost, ecologically friendly, and [11]. Adsorption is the concentration of a substance at the interface of a solid, liquid, or gas phase caused by surface forces. This technique, known for its simplicity and versatility, has several advantages, including cheap cost, insensitivity to pollutants, and ease of operation [12].

The selection of adsorbents is critical to efficient adsorption because they should be versatile, cost-effective, have a high adsorption capacity,

and be reusable [13]. Wastewater treatment employs a variety of adsorbents, including bio-sorbents, carbon-based nano-adsorbents, and polymer-based adsorbents, with activated carbon-based compounds receiving substantial attention due to their chemical stability and high surface area [14].

The creation of metal-doped nanoparticles using techniques such as co-precipitation presents a promising path for wastewater remediation [15]. Metal-doped nanoparticles, such as Mg-doped CuO nanoparticles, have improved dye removal characteristics in wastewater [16].

Doping, which includes introducing impurities into host lattices, is a typical technique for modifying the optical and chemical properties of nanomaterials [17]. Metal-doped nanoparticles, such as Cu-doped FeO nanoparticles, have demonstrated outstanding performance in the removal of organic dyes from wastewater, indicating their potential for wastewater treatment applications [18].

In this study, we seek to evaluate the efficient adsorption of Methylene Blue dye using Mg-doped CuO nanoparticles, proposing a unique way for effective wastewater treatment [19]. Through rigorous experimentation and analysis, we hope to determine the efficacy of Mg-doped CuO nanoparticles in eliminating Methylene Blue dye from wastewater, thereby contributing to the evolution of sustainable water treatment methods.

2. METHODOLOGY

2.1 Materials

Magnesium chloride hexahydrate $MgCl_2.6H_2O$, copper chloride $CuCl_2$, sodium hydroxide NaOH, and deoxygenated distilled water were used to synthesize Mg-doped CuO nanoparticles.

2.2 Synthesis

Mg-doped CuO nanoparticles were synthesized using a basic co-precipitation technique [20]. In 100 mL of distilled water, 7.8 g of magnesium chloride hexahydrate and 3.5 g of copper chloride were dissolved. To bring the pH to around 10, a 0.2M solution of sodium hydroxide (NaOH) was gently added to the salt solution while stirring constantly. The resultant solution was then thermally treated at 80 °C for 3 hours to promote precipitate formation [21]. Following that, the solution was left to stand overnight, and the precipitates were cleaned with water and alcohol. The resulting product was then dried at 120°C for 3 hours before being calcined at 400°C for around 4 hours to produce Mg-doped CuO nanoparticles [21].

2.3 Batch Adsorption Experiment

A series of batch adsorption studies were carried out to determine the adsorption efficiency of Mg-doped CuO nanoparticles for the removal of methylene blue. Initially, a stock solution of 1000 ppm methylene blue dye was made by dissolving 1 g of the dye in distilled water to a final volume of 1000 ml in a measuring flask. Using the dilution formula ($C_1V_1=C_2V_2$), dye solutions with concentrations of 10 ppm, 20 ppm, 30 ppm, 40 ppm, and 50 ppm were created from this stock solution.

The pH of the dye solutions was changed with 0.1 M NaOH and 0.1 M HCl solutions to achieve the correct pH values for the adsorption studies. The adsorption tests were carried out to investigate the removal effectiveness of Mg-doped CuO nanoparticles under various experimental conditions, such as dosage rate, concentration, pH, contact time and temperature [22,23]. Overall, the batch adsorption studies were designed to thoroughly evaluate the adsorption efficiency of Mg-doped CuO nanoparticles for methylene blue dye removal under a variety of experimental settings, revealing important information about their prospective application in wastewater treatment [24,25].

3. RESULTS AND DISCUSSION

3.1 Characterization of mg-Doped CuO Nanoparticles

3.1.1 SEM

Scanning electron microscopy (SEM) is a sophisticated imaging technology that uses a focused beam of electrons to produce high-resolution pictures of material samples [26]. As the electron beam interacts with the atoms in the sample, a variety of signals are released, providing useful information on the material's composition and surface structure. The electron beam is traversed across the sample in a raster scan pattern, and the detected signals' intensities are used to create an image [27]. To create the image, the most commonly used SEM mode detects secondary electrons emitted from the

sample's atoms [28]. Among other parameters, the topography of the sample surface influences the amount of secondary electrons detected, and hence the signal strength [29]. SEM examination was performed to analyze the morphology of Mg-doped CuO nanoparticles [30]. The obtained images are provided below at various resolutions (1µm, 2µm, 200nm, and 500nm). The SEM photos show that Mg-doped CuO nanoparticles have a variety of morphologies, including spherical forms and aggregates. At lower magnifications, the nanoparticles appear to aggregate, which could be owing to particle interactions or the presence of voids created during synthesis. However, higher magnification photos show that these aggregated nanoparticles are made up of smaller, more homogenous nanoparticles that form spherical clusters.

Overall, SEM examination gives useful information about the morphology and structure of Mg-doped CuO nanoparticles, emphasizing their potential uses in a variety of domains such as wastewater treatment and catalysis [31].

3.1.2 EDX analysis

Energy-dispersive X-ray spectroscopy (EDX) is a potent technique for determining the elemental makeup of materials, even in minute amounts, usually within a few cubic micrometers [32]. When a sample is attacked with electrons from an electron beam in a suitably equipped scanning electron microscope (SEM), the atoms on the surface get excited and generate characteristic X-ray wavelengths that are particular to the elemental structure present [33]. These produced X-rays are then detected and examined by an energy-dispersive detector, which can discriminate between various X-ray energies [34]. In the case of Mg-doped CuO nanoparticles, EDX analysis was used to identify the elemental configurations present in the sample based on atomic and weight percentages. The research found that oxygen, iron, and copper were the main components, with varied weights and atomic percentages. Oxygen accounted for the biggest weight percentage (27.97%), followed by iron (30.73%) and copper (41.30%). In terms of atomic percentages, iron accounted for the majority (6.11%), followed by oxygen (68.45%) and copper (25.44%) [35]. The EDX spectra generated from the analysis showed peaks corresponding to the characteristic X-ray emissions of each element present in the sample, which were consistent with their keV values. This research sheds light on the elemental composition and distribution of Mg-doped CuO nanoparticles, allowing for a more comprehensive knowledge of their properties and prospective applications [19].

3.1.3 FTIR analysis

Fourier Transform Infrared (FTIR) spectroscopy is a valuable technique for determining the chemical structure and bonding of materials, including doped nanoparticles such as Mg-doped CuO. FTIR spectra of pure CuO reveal peaks at ~443 cm^{-1} (Cu-O stretching vibrations) and ~495 cm^{-1} (Cu-O bending vibrations). Doping with Mg^{2+} can cause shifts in these peaks due to changes in the immediate environment surrounding the CuO lattice [36].

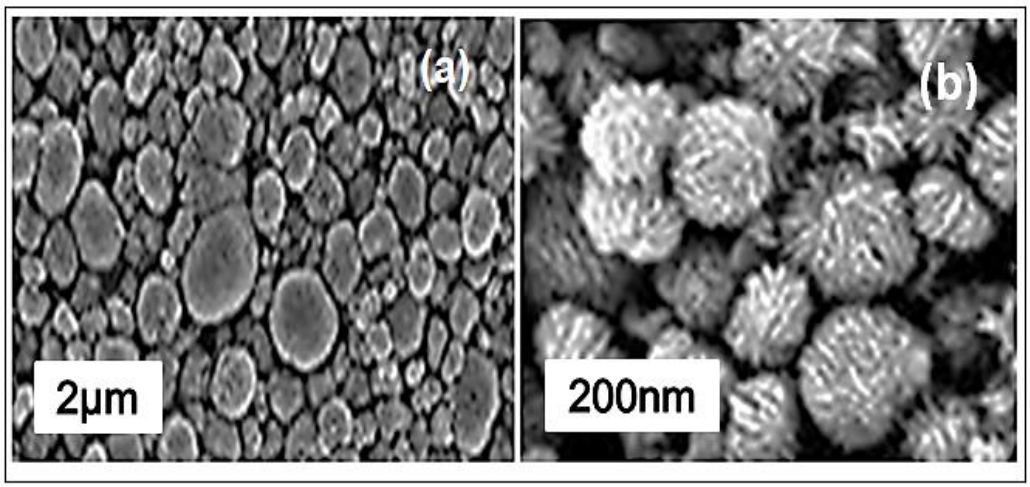

Fig. 1. SEM images of Mg-doped CuO Nanoparticles at 2µm and 200nm

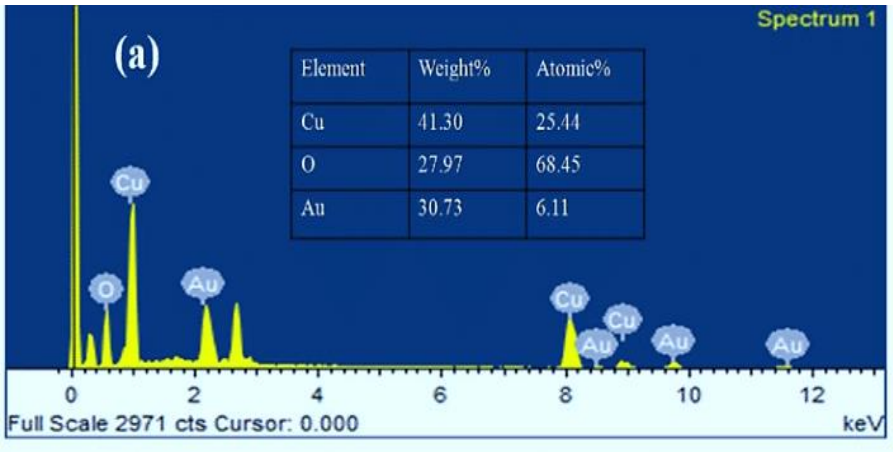

Fig. 2. EDX Spectra of Mg-doped CuO Nanoparticles

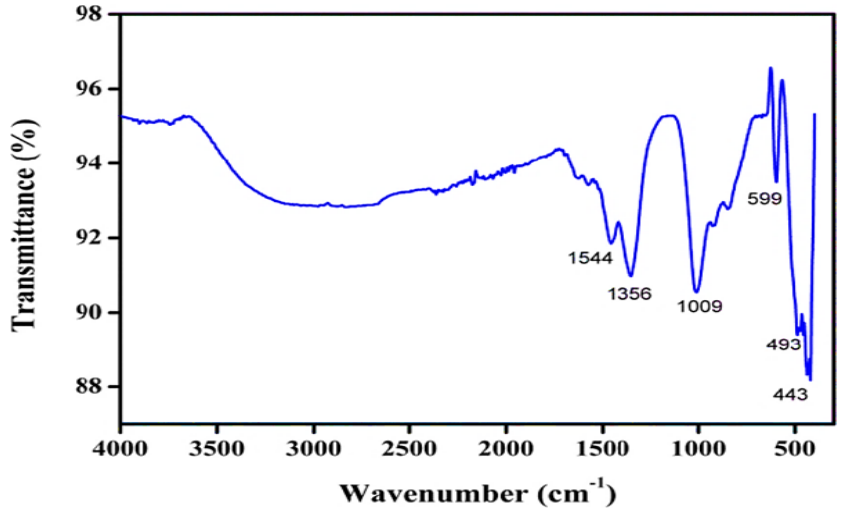

Fig. 3. FTIR Spectra of Mg-doped CuO Nanoparticles

Additional peaks or changes in intensity could indicate the inclusion of Mg ions into the CuO structure. A change in the characteristic Cu-O peaks could indicate a substitution of Cu^{2+} ions with Mg^{2+} ions in the lattice. The formation of additional peaks may be attributed to vibrational modes associated with Mg-O bonds or doping-induced defect sites. Peak intensity variations can reveal the degree and amount of doping. Shifted peaks at 599 cm^{-1} indicating the presence of Mg doping [37].

4. CALIBRATION CURVE FOR METHYLENE BLUE DYE

Equation of Calibration for Methylene Blue Dye using Beer-Lambert's law, we create a calibration curve for Methylene Blue dye. In order to verify a linear connection, this procedure entails making solutions of Methylene Blue in various concentrations, measuring their absorbance, and graphing the findings [38]. In Standard Solution Preparation we make a stock solution of Methylene Blue by dissolving a predetermined amount of the dye in purified water. By diluting the stock solution with distilled water, we create a range of standard solutions with varying concentrations (e.g., 1, 2, 3, 4, 5 mg/L). The calibration curve equation is expressed as $A=\epsilon cl$A=ϵcl, in which AA represents absorbance, ϵϵ denotes the molar absorptivity coefficient, cc signifies concentration, and ll identifies the path length of 1 cm.

4.1 Effect of pH on Adsorption of Methylene Blue

The pH of the solution is critical to the adsorption effectiveness of Methylene Blue onto Mg-doped CuO nanoparticles [35]. The adsorption of

Methylene Blue was investigated in this work over a pH range of 3 to 9 to discover the optimum pH. The results revealed that pH had a substantial influence on adsorption capacity, with the maximum adsorption occurring at pH 5. At lower pH levels, the surface of Mg-doped CuO nanoparticles becomes positively charged, increasing the electrostatic interaction between negatively charged dye molecules and the adsorbent surface. However, as the pH rises above 7, adsorption effectiveness decreases due to diminished electrostatic attraction and possible competition between hydroxyl ions and dye molecules for active adsorption sites [19]. The optimal pH of 5 resulted in the maximum adsorption capacity of 42.15 mg/g, indicating ideal conditions for dye removal. This finding emphasizes the necessity of maintaining acidic conditions for maximum adsorption performance, making Mg-doped CuO a potential material for wastewater treatment applications.

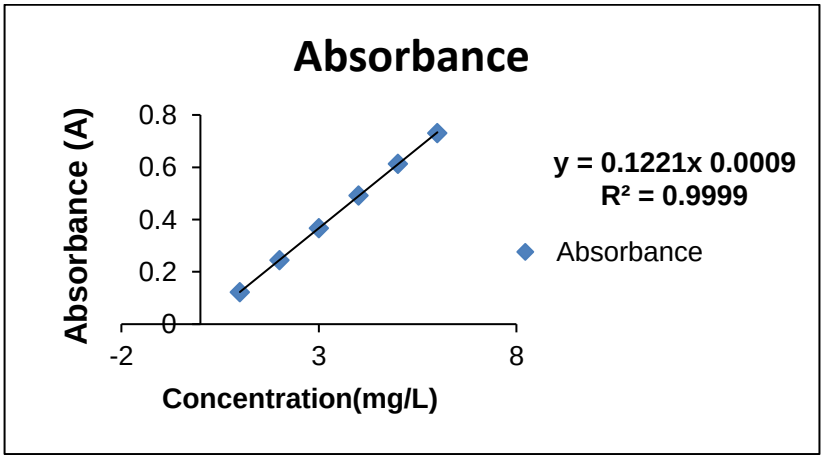

Fig. 4. Calibration Curve for Methylene Blue Dye

Table 1. Absorbance against different concentration

Concentration (mg/L)	Absorbance
1	0.122
2	0.245
3	0.367
4	0.492
5	0.613

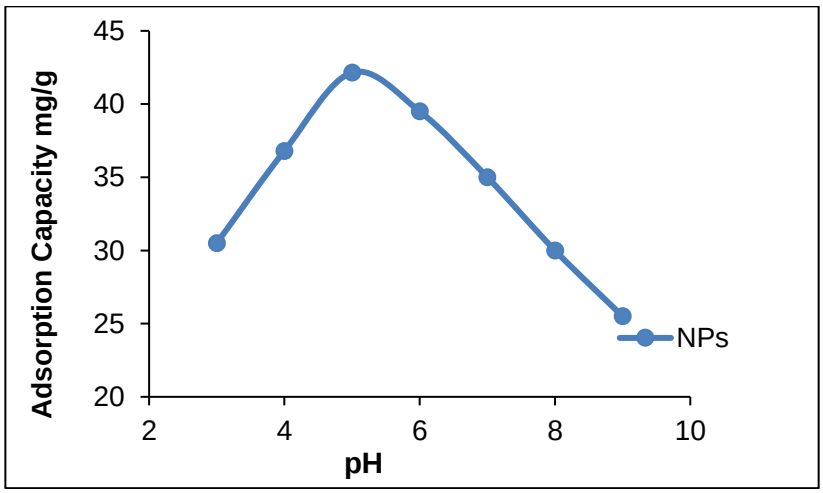

Fig. 5. Effect of pH on Methylene Blue Dye

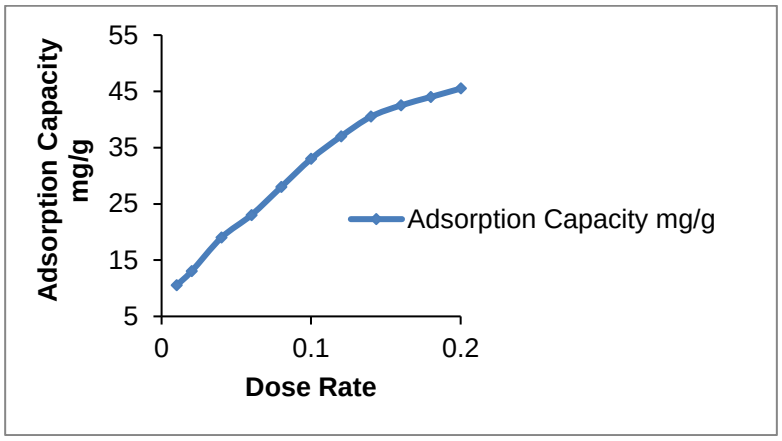

Fig. 6. Effect of dose rate on Methylene Blue dye

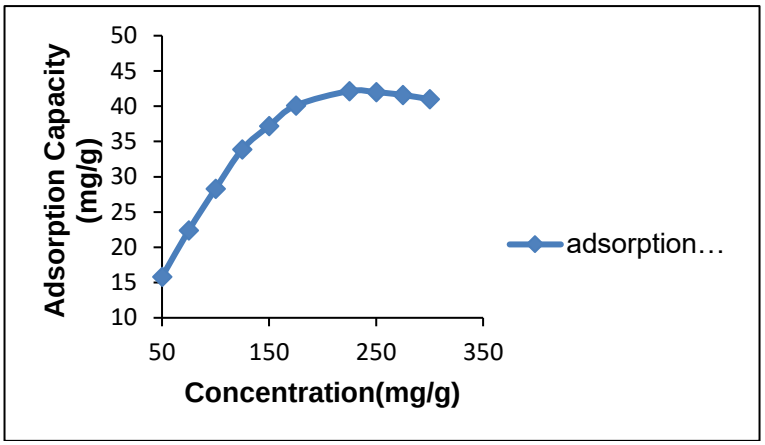

Fig. 7. Effect of Concentration on Methylene Blue Dye

4.2 Effect of Dose Rate on Adsorption Capacity

The dosing rate of Mg-doped CuO nanoparticles had a substantial impact on the adsorption capacity of Methylene Blue dye. As the dose rate rose, there was an initial noticeable increase in adsorption capacity, which can be attributed to the increased availability of active adsorption sites on the nanoparticle surface. However, after a certain dose rate, the adsorption capacity began to plateau [39]. This saturation effect is most likely caused by the overlapping or aggregation of adsorption sites at increasing nanoparticle concentrations, limiting the effective surface area available to dye molecules. The best dosing rate was found to be 0.1 g/50 mL, resulting in the maximum adsorption capacity of 42.15 mg/gram [40]. Further dose rate increases did not result in significant improvements in adsorption efficiency, showing that the excess adsorbent did not contribute proportionally to the dye removal process. This trend emphasizes the significance of optimizing adsorbent dosage in wastewater treatment applications to achieve a balance of efficiency and cost effectiveness [40].

4.3 Effect of Initial Dye Concentration on Adsorption Capacity

The initial dye concentration is crucial for determining the adsorption capacity of Mg-doped CuO nanoparticles. As the starting concentration of Methylene Blue grew, so did the nanoparticles' adsorption capacity, which peaked before stabilizing. At lower concentrations, the number of accessible dye molecules was minimal in comparison to the nanoparticles' plentiful adsorption sites, resulting in high adsorption efficiency [39].

However, as the initial concentration increased, the accessible adsorption sites became saturated, resulting in a gradual leveling of the adsorption capacity. A dye concentration of 200 ppm resulted in a maximum adsorption capacity

of 42.15 mg/g. Beyond this concentration, the increase in dye molecules did not lead to a substantial increase in adsorption capacity, indicating that the adsorbent sites were fully used. This trend shows that the adsorption process is heavily reliant on the balance of available adsorption sites and dye molecules, making initial dye concentration optimization critical for efficient wastewater treatment.

5. CONCLUSION

This study shows that Mg-doped CuO nanoparticles can be excellent adsorbents for removing synthetic colors from wastewater. Under optimal conditions, the produced nanoparticles demonstrated outstanding adsorption capabilities, particularly for Methylene Blue, indicating their applicability for practical wastewater cleanup applications. The ideal removal conditions—pH 5, 0.1 g/50 mL adsorbent dosage, 120 minutes contact duration, and 200 ppm dye concentration—show that operational parameters have a considerable influence on adsorption performance. The kinetic and equilibrium calculations indicated that the adsorption process followed a pseudo-second-order kinetic model, with the Langmuir isotherm best describing monolayer adsorption on a homogeneous surface. Furthermore, the investigation of electrolyte effects and the identification of 1 N HCl as an effective desorbing agent highlight the nanoparticles' potential for regeneration and reuse, which increases their economic viability. These findings suggest that Mg-doped CuO nanoparticles are a viable, cost-effective, and environmentally acceptable alternative to traditional wastewater treatment technologies for color removal. The remarkable adsorption capability, together with the ease of synthesis and regeneration, highlights their relevance in tackling the ongoing problem of dye pollution in water. Future study should concentrate on scaling up the technique, measuring the removal effectiveness of other contaminants, and determining the long-term environmental impact of using these nanoparticles. Finally, the use of Mg-doped CuO nanoparticles in water treatment technologies has the potential to significantly improve water quality and promote long-term environmental management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Forslund A, et al, Securing water for ecosystems and human well-being: The importance of environmental *flows.* Swedish Water House Report. 2021;24:1-52.
2. Young SL et al. Perspective: The importance of water security for ensuring food security, good nutrition, and well-being. Advances in Nutrition, 2021;12(4): 1058-1073.
3. Aslam S, et al, Sustainable model: Recommendations for water conservation strategies in a developing country through a psychosocial wellness program. Water. 2021;13(14):1984.
4. Kumar S. Smart and innovative nanotechnology applications for water purification. Hybrid Advances. 2023;3: 100044.
5. Anand A, Rajchakit U, Sarojini V. Detection and removal of biological contaminants in water: the role of nanotechnology, in Nanomaterials for the detection and removal of wastewater pollutants., Elsevier. 2020;69-110.
6. Hanif MA, et al., Applications of coagulation -flocculation and nanotechnology in water treatment, in Aquananotechnology, Elsevier. 2021;533-558.
7. Pandey NK, Gupta P, *Societal* impact of nanomaterials. Versatile Solicitations of Materials Science in Diverse Science Fields. 2021;1.
8. Nair VK., et al., Phycoremediation of synthetic dyes laden textile wastewater and recovery of bio-based pigments from residual biomass: An approach towards sustainable wastewater management. Processes. 2023;11(6):1793.
9. House M. et al., Urban drainage-impacts on receiving water quality. Water Science and technology. 1993;27(12):117.
10. Akpor O. Muchie B. Environmental and public health implications of wastewater quality. African Journal of Biotechnology. 2011;10(13):2379-2387.

11. Yuan H, He Z. Integrating membrane filtration into bioelectrochemical systems as next generation energy-efficient wastewater treatment technologies for water reclamation: A review. Bioresource Technology, 2015;195:202-209.
12. Barakan S, Aghazadeh V. The advantages of clay mineral modification methods for enhancing adsorption efficiency in wastewater treatment: A review. Environmental Science and Pollution Research. 2021;28(3):2572-2599.
13. Montes-Atenas G, Valenzuela F. Wastewater treatment through low-cost adsorption technologies. Physico-Chemical Wastewater Treatment and Resource Recovery. 2017:214-238.
14. Crini G., et al., Conventional and non-conventional adsorbents for wastewater treatment. Environmental Chemistry Letters. 2019;17:195-213.
15. Rafiq A, et al., Study of transition metal ion doped CdS nanoparticles for removal of dye from textile wastewater. Journal of Inorganic and Organometallic Polymers and Materials. 2020;30:1915-1923.
16. Guo Z, et al., Integration of green energy and advanced energy-efficient technologies for municipal wastewater treatment plants. International Journal of Environmental Research and Public Health. 2019;16(7):1282.
17. Ray SK, Cho J, Hur J, A critical review on strategies for improving efficiency of BaTiO3-based photocatalysts for wastewater treatment. Journal of Environmental Management. 2021;290: 112679.
18. Natarajan S, Bajaj HC, RJ. Tayade, Recent advances based on the synergetic effect of adsorption for removal of dyes from waste water using photocatalytic process. Journal of Environmental Sciences. 2018;65:201-222.
19. Adnan RM., et al., Synthesis, characterization, and antibacterial activity of Mg-doped CuO nanoparticles. Molecules. 2022;28(1):103.
20. Dong H, Koenig GM. A review on synthesis and engineering of crystal precursors produced via coprecipitation for multicomponent lithium-ion battery cathode materials. Cryst Eng Comm. 2020;22(9): 1514-1530.
21. Din SU., et al. One step facile synthesis, characterization and antimicrobial properties of Mg-doped CuO nanostructures. Materials Research Express. 2019;6(8):085022.
22. Biltayib BM., et al., Predictive modeling and simulation of wastewater treatment process using nano-based materials: Effect of pH and adsorbent dosage. Journal of Molecular Liquids. 2021;343: 117611.
23. Padmavathy K, Madhu G, Haseena P. A study on effects of pH, adsorbent dosage, time, initial concentration and adsorption isotherm study for the removal of hexavalent chromium (Cr (VI)) from wastewater by magnetite nanoparticles. Procedia Technology. 2016;24:585-594.
24. Nyamaka PR. Treatment & value recovery from mining wastewater rich in sodium chloride and Sodium Sulphate;2024.
25. Zaldivar-Díaz JM. et al., Synergistic electrocoagulation–precipitation process using magnesium electrodes for denim wastewater treatment: Bifunctional support electrolyte effect. Journal of Water Process Engineering. 2023;51:103369.
26. Memon MA, et al., PLS-SEM statistical programs: A review. Journal of Applied Structural Equation Modeling. 2021;5(1):1-14.
27. Russo D, Stol KJ. PLS-SEM for software engineering research: An introduction and survey. ACM Computing Surveys (CSUR). 2021;54(4):1-38.
28. Dash G, Paul J, CB-SEM vs PLS-SEM methods for research in social sciences and technology forecasting. Technological Forecasting and Social Change. 2021; 173:121092.
29. Mahltig B, Grethe T. High-performance and functional fiber materials—A review of properties, scanning electron microscopy SEM and electron dispersive spectroscopy EDS. Textiles. 2022; 2(2):209-251.
30. Dery B, Zaixiang L. Scanning Electron Microscopy (SEM) as an effective tool for determining the morphology and mechanism of action of functional ingredients. Food Reviews International. 2023;39(4):2007-2026.
31. Oliveira AG., et al. Wastewater treatment using Mg-doped ZnO nano-semiconductors: A study of their potential use in environmental remediation. Journal of Photochemistry and Photobiology A: Chemistry. 2021;407: 113078.
32. Hodoroaba VD, Energy-dispersive X-ray spectroscopy (EDS), in Characterization of

Nanoparticles. 2020, Elsevier. 2020;397-417.
33. Kara U. et al., Scanning electron microscopy (SEM), energy-dispersive X-ray (EDX) spectroscopy and nuclear radiation shielding properties of [α-Fe3+ O (OH)]-doped lithium borate glasses. Applied Physics A. 2020;126:1-14.
34. Khan MSI, SW. Oh, Kim YJ, Power of scanning electron microscopy and energy dispersive X-ray analysis in rapid microbial detection and identification at the single cell level. Scientific Reports. 2020;10(1):2368.
35. Azharudeen AM., et al. Solar power light-driven improved photocatalytic action of mg-doped cuo nanomaterial modified with polyvinylalcohol. Journal of Nanomaterials. 2022;2022(1): 2430840.
36. Fadlelmoula A., et al., Fourier transform infrared (FTIR) spectroscopy to analyse human blood over the last 20 years: A review towards lab-on-a-chip devices. Micromachines. 2022;13(2): 187.
37. Thangavel K, et al., Synthesis and characterization of pure and magnesium (Mg) doped CuO nano particles by solid state method. Sensor Letters. 2020;18(2): 137-142.
38. Fernández-Pérez A, Marbán G. Visible light spectroscopic analysis of methylene blue in water. Journal of Applied Spectroscopy. 2022:1-7.
39. Subash M, et al., Pseudo-first kinetics model of copper doping on the structural, magnetic, and photocatalytic activity of magnesium oxide nanoparticles for energy application. Biomass Conversion and Biorefinery. 2023;13(4):3427-3437.
40. Chandekar KV., et al., Photocatalytic activities of Mg doped NiO NPs for degradation of Methylene blue dye for harmful contaminants: A kinetics, mechanism and recyclability. Journal of Physics and Chemistry of Solids. 2023;178:111345.

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