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Copper Oxide a Efficient Visible Light Photocatalyst For Dye Degradation

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ABSTRACT

CuO nano powder was prepared by a simple synthetic route involving hydrothermal method at 120 °C, and that was characterized by number of techniques, such as XRD, FESEM, and UV-vis DRS. UV-vis DRS and showed a reflection edge with corresponding energy at 2.2 eV. The photocatalytic degradation activity of the CuO nano powder was tested against the elimination of MB dye under sunlight exposure. About 65% degradation of MB dye is observed in 150 min.

Keywords: CuO, Nanomaterials, Sunlight

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INTRODUCTION

Water is vital for life and human progress. This study focuses on the impact of industrial dye release and the necessary bioremediation processes. Excessive use of organic dyes in textile and fabric industries leads to water contamination, including micropollutants like persistent organic and inorganic pollutants, endocrine-disrupting chemicals, and pharmaceuticals. Though their small concentration, these pollutants pose a high risk, causing significant environmental damage[1–3].

RB 5, AY-23, and MB azo dyes find extensive application in commercial environments due to their vivid hues, solubility, and capacity to bond effortlessly with fibres. However, during the dyeing process, a portion of these dyes remains in fabrics and gets washed out, leading to high concentrations in textile effluents [4,5]. These effluents contain reactive, acidic, flammable, corrosive, and poisonous compounds that must be decontaminated before reintroduced them into water sources to avoid adverse effects on humans, animals, and the environment. The occurrence of these water pollutants compromises the aesthetic quality of water bodies, increases biochemical and chemical oxygen demand, disrupts photosynthesis, inhibits plant growth, enters the food chain, and can lead to toxicity, mutagenicity, and carcinogenicity. Additionally, other types of waste, like oil and grease, pose challenges as they accumulate on the water's surface, reducing light availability for aquatic plants and posing risks to fish and birds [6–9].

Heavy metals, such as lead and mercury, further exacerbate the issue, being harmful to both humans and animals, potentially causing significant health consequences if consumed from polluted water sources. To address these challenges, cost-effective and eco-friendly treatments are needed. Metal oxide nanomaterials have been proposed for their

unique properties and promising applications in various chemical processes, including Fenton, defoamation, and adsorption, to decolorize water pollutants through transition metal oxide catalysis. Although, these methods have limitations such as slow reaction rates, complex chemistry, and the production of metal ion sludge. Heterogeneous catalysis has emerged as a green technology that efficiently mineralizes organic pollutants using light irradiation, offering a promising solution to mitigate water pollution [10–12].

The effectiveness of catalysis relies on several environmental variables, encompassing the surface charge and electronic configuration of the catalyst, the characteristics of the active surface site, pH levels, temperature, synthesis technique, and the dimensions of the photo reactant. Cupric Oxide (CuO) is widely used as a benchmark photocatalyst for photodegradation due to its nanostructure. CuO is highly reactive and is a lower band gap semiconductor with a monoclinic structure. It efficiently absorbs a significant portion of the solar spectrum and has a high surface volume, making it suitable for various catalytic applications. CuO emerges as an economical, environmentally friendly, and readily available substance, rendering it suitable to produce nanoparticles through sustainable methods [13–15]. Through chemically reduction processes, CuO nanoparticles exhibit impressive photocatalytic activity, achieving around 82% decolorization of dyes under UV light irradiation. In specific conditions, such as heating to 600°C, the decolorization of MB reached as high as 93% within 120 minutes using electrochemically prepared CuO nanoparticles. A simple and eco-friendly hydrothermal method has been introduced for the synthesis of copper oxide nanoparticles. These nanoparticles have a bandgap energy ranging from 1.2 to 2.6 eV, which varies based on preparation conditions and typically demonstrate p-type conductivity due to the developement of copper vacancy defects. This work involves the synthetic strategies and modification methods for CuO fabrication, emphasizing their potential applications in water treatment. Additionally, it discusses advanced techniques like binary and ternary heterojunction formation, Z-scheme-based photocatalytic systems, incorporation of rare earth/transition metal ions as dopants, and the use of carbonaceous materials as support systems to enhance CuO's efficacy in water treatment processes [16,17].

The understanding of photo-induced charge separation and transfer, as well as the involvement of reactive radical species in photocatalytic reactions, has been thoroughly investigated. While various methods and laboratory conditions have enhanced the photocatalytic activity of CuO, the system still faces limitations such as high cost and complex synthesis processes, as well as instability during photochemical operations [18]. To tackle these obstacles, researchers have devised a chemical precipitation technique as a straightforward and ecofriendly method for developing copper oxide nanoparticles. This method utilizes chemical entities like copper (II) nitrate trihydrate as a precursor, resulting in nanoparticles with efficient photocatalytic activity [19]. For instance, CuO nanomaterials synthesized through hydrothermal precipitation showed approximately 65% efficiency in decolorizing tartrazine under sunlight exposurewithin 3 hours. The importance of chemical precipitation in the synthesis of copper oxide nanoparticles, highlighting its eco-friendly nature, and evaluates its effectiveness in catalytically reducing organic dyes such as RB-5, MB, and AY-23 from liquid phases through heterogeneous photocatalysis [20].

METHODOLOGY

Synthesis of CuO nanoparticles

Firstly, 0.2 M of $CuCl_2.H_2O$ (Copper Chloride dihydrate) was mixed in 30 mL 0.4 M sodium hydroxide of deionized water. After stirring both the solutions for 30 min separately, with continuous magnetic stirring. After 1 hr constant stirring, the mixture was poured into a Teflon-lined stainless-steel autoclave and heated under a controlled temperature of 120 °C for 15 h. The resultant precipitates were washed through DI water and C_2H_5OH and was taken in an oven to dry at 50 °C. The synthesized product act as the photocatalyst which is then used for the deterioration of dyes. The synthesis route is as shown in Figure 1.

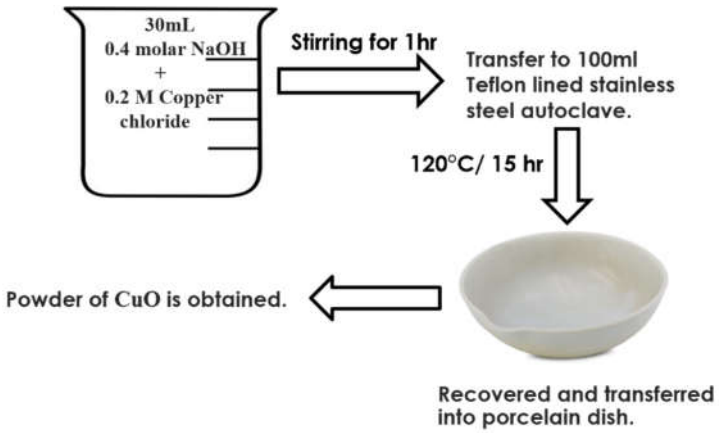

Figure 1: Synthesis route of CuO Nano powders

RESULTS AND DISCUSSIONS

XRD analysis

The XRD plot of Copper Oxide was recorded on X-ray diffractometer. The XRD peaks for CuO were detected at 2θ = 2θ=13.5°, 25.4°, 33.2°, 35.6°, 47.3°, 50.7° and 52.7° which are matched to (0 0 1), (1 0 0), (0 0 2), (1 0 1), (0 0 3), (1 1 0) and (1 1 1) monoclinic planes of Copper Oxide (Card No.-89-1758) (Figure.2).

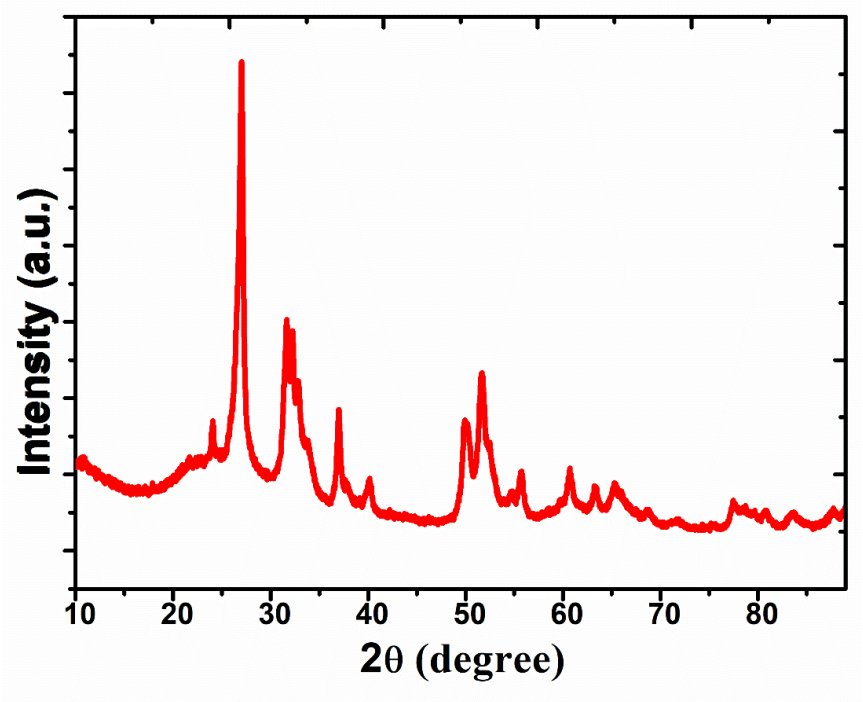

Figure 2: XRD CuO nanoparticles

FE-SEM analysis of Copper Oxide

The FE-SEM image of CuO nanoparticles was recorded by analysing electron microscope, shows nanoplate-like structures with a diameter in the range of 70-90 nm (Figure. 3). The FESEM indicates the agglomerated nanoparticles of copper oxide, which confirm the high adsorption of dye molecules which result in the good removal of dye molecule from the waste water.

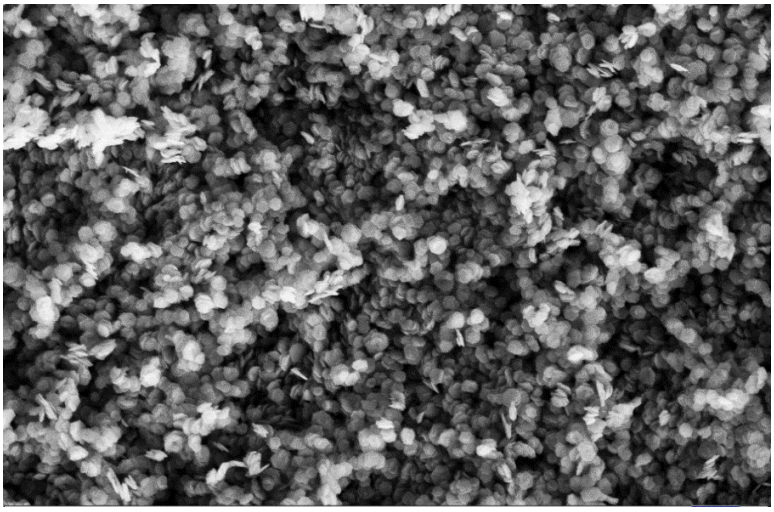

Figure 3: FE-SEM image of CuO nanoparticles

Optical analysis

The pure CuO nanomaterials which are absorb in the visible light region (Figure.4). The UV-vis DRS spectra were changed into absorption spectra by using (K-M function) Kubelka-Munk [21], and Taucs plots are used to determine the Eg [22], Figure. shows Tauc's plots of CuO photocatalyst. The optical band gap of CuO was determined to be 2.2 eV.

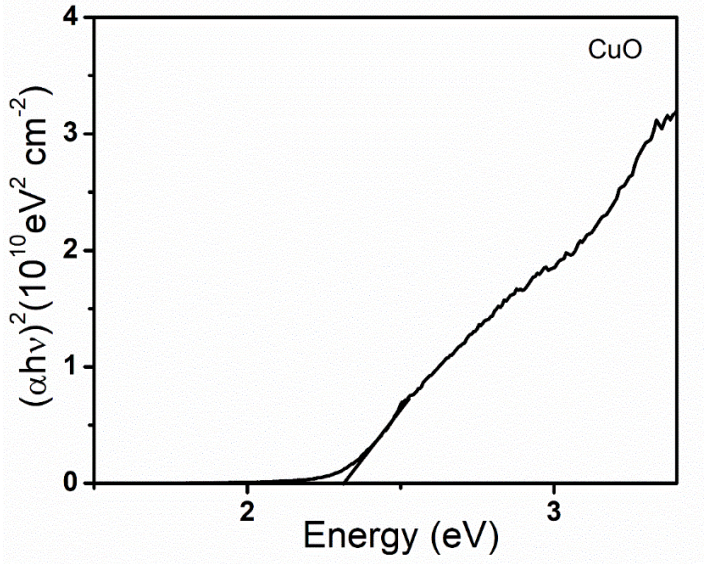

Figure 4: Tauc's plot of pure CuO

Photocatalytic activity

The sunlight-mediated photocatalytic elimination of MB dyes (10 mg/L) by the CuO nanomaterials is depicted in Figure. 5. The CuO nanomaterials show the photo chemical completion of about 65 % MB dye degradation after 150 min of sunlight exposure. Figure.5 displays the UV-vis absorption spectra, during the photocatalytic degradation it shows the change in concentration of MB dye. There is a downfall in the absorption peak of **MB** dye (664 nm) was observed over 150 min period of sunlight irradiation

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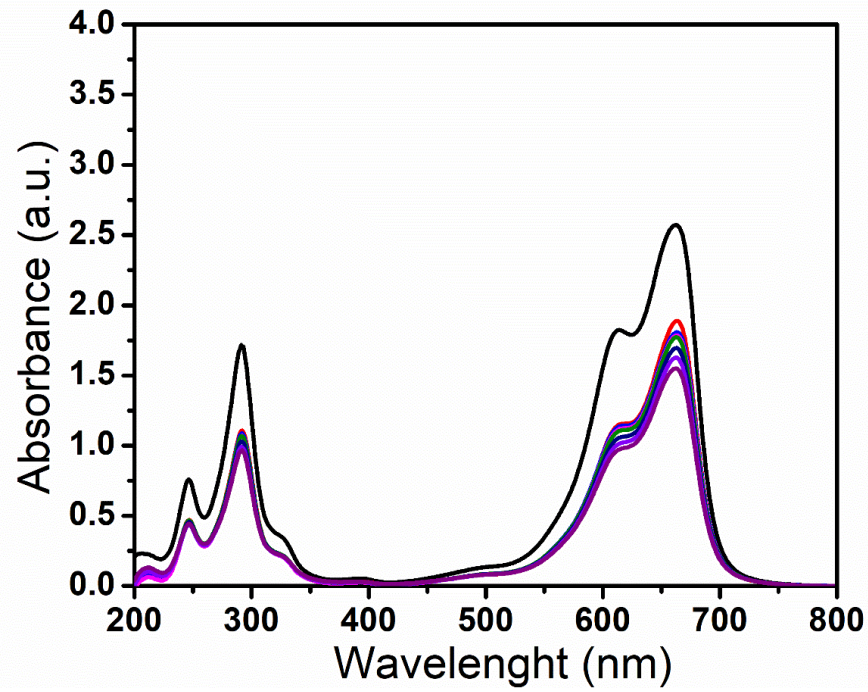

Figure 5: UV-is absorbance spectra of MB dye solution

CONCLUSIONS

CuO nanomaterials as a photocatalyst was synthesis by a straightforward hydrothermal synthetic route. The copper oxide photocatalyst shows photocatalytic performance towards the degradation of 65 % of methylene blue (MB) under sunlight irradiation. Copper Oxide is an effective visible light photocatalyst option for removing various organic dyes in aqueous media due to its strong photocatalytic activity.

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