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Flower Like Cadmium Cobaltite for Evan's Blue Degradation Through Photocatalytic Process

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ABSTRACT

A visible-light-responsive cadmium cobaltite photocatalyst was synthesized via a simple wet chemical precipitation method and evaluated for the degradation of Evans blue dye. Structural and optical analyses (XRD, FTIR, UV–Vis and SEM) confirmed the formation of a crystalline phase with enhanced visible-light absorption. Under visible-light irradiation, the photocatalyst achieved a maximum degradation efficiency of 96% within 100 min at pH 9, following pseudo-first-order kinetics with an apparent rate constant of 0.0213 min^{-1}. Parametric investigations revealed that alkaline conditions, optimized catalyst dosage and lower initial dye concentration significantly enhanced photocatalytic performance. The improved activity is attributed to efficient photo-induced charge separation and the generation of reactive oxygen species ($^{\bullet}OH$ and $^{\bullet}O_2^-$), which play a dominant role in dye mineralization. Additionally, the catalyst exhibited good photo-stability and reusability, demonstrating its potential for sustainable wastewater remediation.

1. Introduction

Researcher teams of Cooksey and Gelmini et al. [1-4] explained as many blue dyes, including Trypan blue, methylene blue and patent blue were created in the early 1900s. Evan's blue (EB) has been used as a clinical diagnostic agent and biological dye for many years. This synthetic bis-azo dye, commonly known as T-1824 and Direct Blue 53, was first used for staining by Herbert McLean Evan's in 1914. It became well-known when the Eastman Kodak Company promoted it as "Evans blue" in 1936 to recognize Evans' efforts. Since then, "Evans Blue" has gained widespread acceptance.

Kumara et al. [5] and Jithendra Kumara et al. [6] explained as in recent years, there has been a quick and ongoing advancement in nanoparticle research because of the special qualities of fundamental elements brought about by atomic and molecular changes. Jithendra Kumara et al. [7] explained as because of these unique qualities, nanoparticles are now used in various industries, such as plastics, coatings, electronics, cosmetics, medicine and agriculture. Many industries use organic dyes, shown in table 1, including textiles, optoelectronics, food and cosmetics. M. B. Tahir [8] explained as these industries release organic waste effluents into the environment, which can have a negative effect on the environment. Removing these effluents might be difficult at times.

The calcium ferrite ($CaFe_2O_4$) particles that were produced by a green solution combustion process were used to photo-catalytically breakdown Evan's blue dye. It was done to optimize variables like pH, catalyst dosage and starting dye concentration. The results of the investigation demonstrated that the catalyst might be employed again for up to five cycles of excellent adsorption and dye degradation, demonstrating strong photo-stability as confirmed by Adarsha et al. [9]. Sumadevi et al. [10] explained as the photocatalytic efficacy of ZnS, CO-precipitation-prepared Ag:ZnS nanoparticles capped with polyvinyl alcohol (PVA) and Ag:ZnS nanoparticles without a cap were demonstrated. Eriochrome black-T and Evan's blue dyes are effectively degraded by sunshine, with over 90% breakdown, indicating potential for water cleanup from textile contamination. Table 1 provides the molecular details of few blue dyes.

This work aims to synthesize and systematically evaluate a visible-light-driven cadmium cobaltite photocatalyst for efficient Evans blue dye degradation, with emphasis on kinetic behaviour, operational parameters, and reusability for wastewater remediation.

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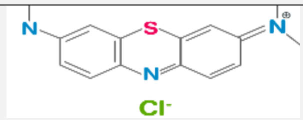
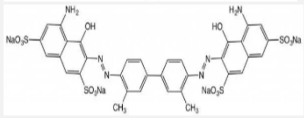
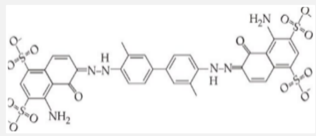
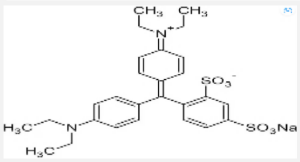
Table 1 Molecular details of some blue dyes

Dye	Molecular formula	Chemical structure	SO_3H groups	λ_{max} (nm)
Methylene Blue	$C_{16}H_{18}ClN_3S$		0	670
Trypan Blue	$C_{34}H_{24}N_6Na_4O_{14}S_4$		4	600
Evans Blue	$C_{34}H_{24}N_6Na_4O_{14}S_4$		4	620
Patent Blue	$C_{27}H_{31}N_2O_6S_2$		2	640

2. Experimental Methods

2.1 Synthesis of $CdCo_2O_4$

Simple chemical reactions and nucleation processes provide the basis for the explanation of the mechanism of $CdCo_2O_4$ production; the flowchart is represented in Fig. 1.

$$\text{Cobalt nitrate (aq)} + \text{NaOH (aq)} \rightarrow Co(OH)_2\ (cp) + NaNO_3\ (l) + H_2O$$

$$\text{Cadmium nitrate (aq)} + \text{NaOH(aq)} \rightarrow Cd(OH)_2\ (cp) + NaNO_3\ (l) + H_2O$$

$$Co(OH)_2\ (cp) + Cd(OH)_2\ (cp) + NaOH\ (l) \rightarrow CdCo_2O_4\ (p) + Na^+ + OH^- + H_2O$$

Using NaOH to hydrolyze the precursors $Cd(NO_3)_2$ and $Co(NO_3)_2$, this procedure produces coagulated precipitates of cobalt hydroxide and cadmium hydroxides, which are unstable intermediates. Precipitation begins when $CdCo_2O_4$ achieves super saturation.

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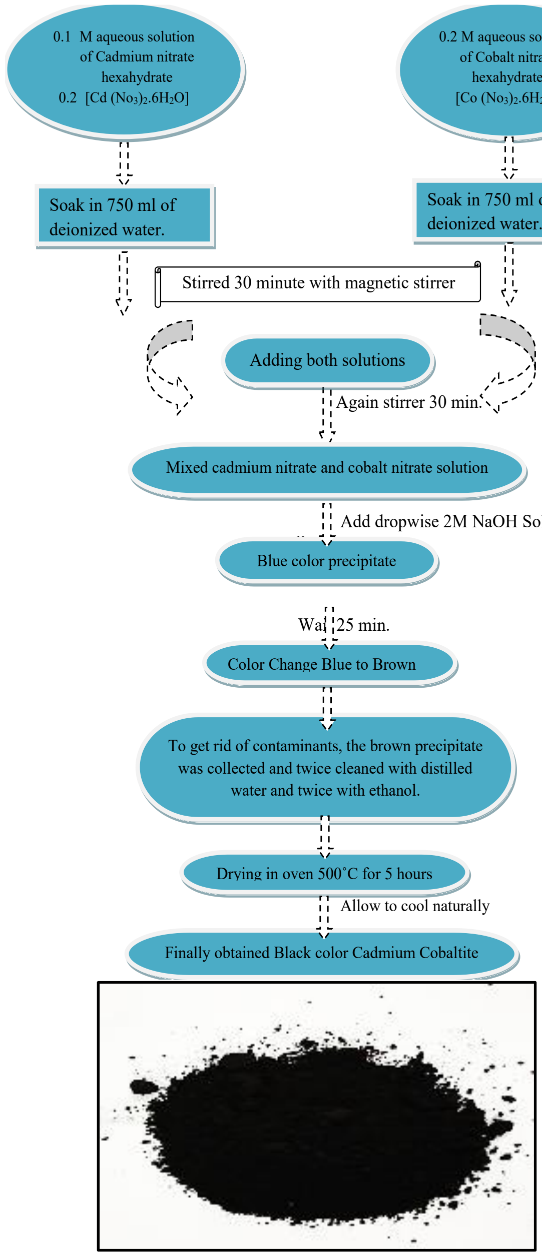

Fig. 1 Flow chart for synthesis of cadmium cobaltite

2.2 Evaluation of Photocatalytic Performance

A 3.0 × 10^{-5} M solution of Evan's blue was divided into four beakers: one kept in the dark, one exposed to light, one with cadmium cobaltite in the dark and one with cadmium cobaltite exposed to light. After 5 hours, only the beaker containing both cadmium cobaltite and light showed a decrease in absorbance, high lighting the necessity of both components for the dye's degradation.

2.3 Photocatalytic Breakdown of Evans Blue Dye using $CdCo_2O_4$ Nanoparticles

Evan's blue dye degradation rate was tracked to assess the photocatalytic activity of the catalyst. A stock solution (1.0 × 10^{-3} M) was prepared by dissolving 0.096 g of dye in 100 milliliters of doubly distilled water. The pH of this solution was adjusted using 0.1 N HCl and 0.1 N sodium hydroxide solutions using a digital pH meter (Systronics model 335). Three milliliter samples were taken out of the reaction mixture containing 0.10 gram of photocatalyst every ten minutes and exposed to a 200 watt tungsten lamp. A spectrophotometer (Systronics Model 106) was used to measure the samples' absorbance (A) at λ_{max} = 620 nm after removing heat radiation using a water filter. The light's intensity was controlled by varying the distance between the lamp and the reaction mixture using a Suryamapi instrument (CEL type SM 201). The absorbance decreased over the course of the experiment, indicating that prolonged exposure times would result in a decrease in the concentration of Evan's blue dye. After 2.30 hours of light, Evan's blue was almost destroyed as shown in Fig. 2. The following formula was used to determine the degradation efficiency,

$$\text{Dye Degradation (\%)} = \text{IOD - FOD/ IOD} \times 100$$

where IOD- Initial optical density and FOD- final optical density.

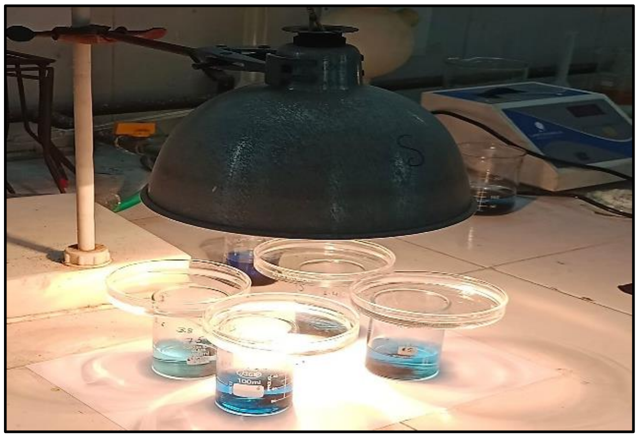

Fig. 2 Practical setup

2.4 Active Species

The impact of active and inactive species on the photocatalytic activity of the cadmium cobaltite catalyst was evaluated by trapping studies. Hydroxyl radicals ($^{\bullet}OH$) and superoxide radicals ($O_2^{-\bullet}$) were studied in order to determine the active species during the process. 10 mM isopropyl alcohol (a quencher of $^{\bullet}OH$) and 10 mM benzoquinone (a quencher of $O_2^{-\bullet}$) were used for the respective investigations. With the exception of adding scavengers before turning on the lamp, the procedure was the same as the one used in the prior degradation test.

2.5 Stability and Reusability

The cadmium cobaltite photocatalyst must be stable for wide-ranging technological applications. To assess this stability, recycling experiments were carried out to cause Evan's blue to deteriorate when exposed to visible light. The cadmium cobaltite was recovered by simple decantation and it was then washed with ethanol and distilled water before being dried at 80 °C in an oven. The sample was then used once again for additional deterioration tests.

3. Results and Discussion

3.1 XRD Characterization

An efficient method for analyzing the crystal structure and phase purity of materials is X-ray diffraction (XRD). The XRD pattern's distinct peaks can confirm that a pure phase of cadmium cobaltite was synthesized. The average grain size of nanocrystalline materials is frequently calculated using the Debye-Scherrer formula from the obtained XRD patterns. Debye-Scherrer formula was used to establish a connection between the Full Width at Half Maximum (FWHM) of the XRD peak and the average crystalline size (D) of a nanocrystalline material. The average crystalline size of the catalyst from Fig. 3 is determined to be 28 nm. Adam et al. [11] also explained the structural characteristics of cadmium cobaltite as like this present observation.

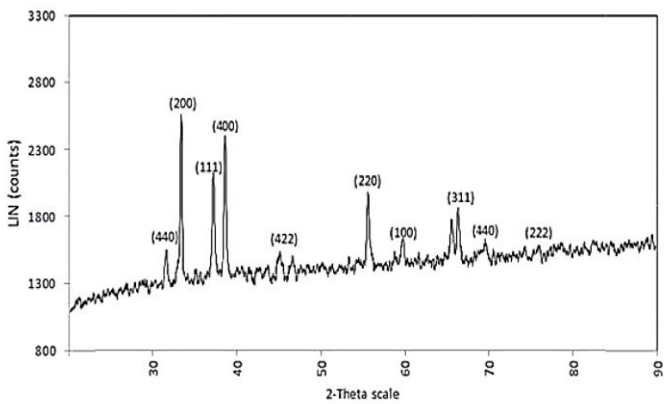

Fig. 3 XRD pattern for synthesised cadmium cobaltite

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3.2 FT-IR Analysis

The synthesized $CdCo_2O_4$ catalyst's FT-IR spectra in the 400 cm^{-1}- 4000 cm^{-1} wavelength range are displayed in Fig. 4. Wei et al. [12] explained as the two prominent transmittance bands in the FTIR spectra of the $CdCo_2O_4$ catalyst, located at 560 and 659 cm^{-1} are indicative of the catalyst's spinel structure. The peak at 560 cm^{-1} was found to be caused by the M–O stretching vibration of octahedrally coordinated cobalt ions. The band at 659 cm^{-1} was generated by the M-O stretching vibration of the tetrahedrally coordinated cadmium ion. Xia et al. [13] explained as the stretching vibration of NO_3^-, corresponding to the peak at 1401 cm^{-1}, is present because of the Co $(NO_3)_2$ residue. Kaviyarasu et al. [14] explained as the peak at 791 cm^{-1} is attributable to CdO. The FTIR spectra of $CdCo_2O_4$ also showed stretching vibration bands at 2988 cm^{-1} and 2366 cm^{-1}, which correspond to the C–H and C=O functional groups, respectively.

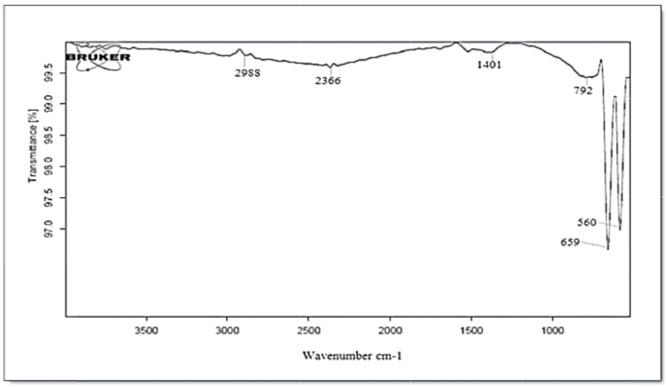

Fig. 4 FT-IR spectrum for synthesised cadmium cobaltite

3.3 FESEM and EDX Analysis

The FESEM images in Fig. 5 display the elemental peaks of the $CdCo_2O_4$ sample produced via the co-precipitation method, as revealed by EDX analysis. At approximately 500 °C, a flower-like structure was observed. Elemental analysis and FESEM were conducted using the EDX approach, which clearly showed the elemental peaks of $CdCo_2O_4$. Table 2 illustrates the EDX spectrum and confirmed the phase purity of the catalyst, aligning well with the XRD results by not detecting any additional components.

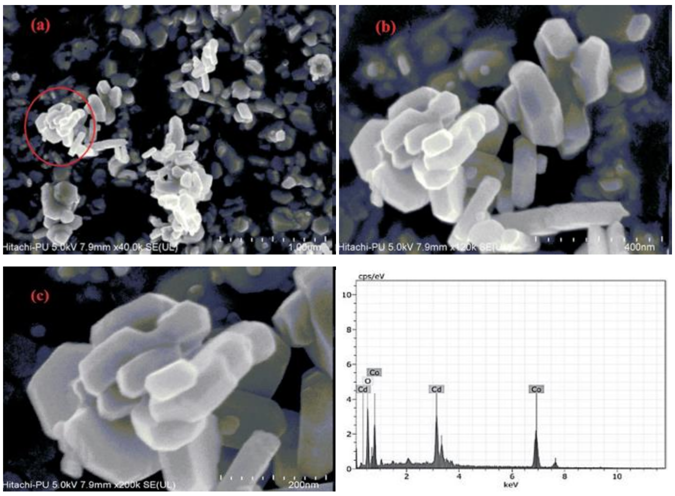

Fig. 5 FESEM and EDX image of synthesized $CdCo_2O_4$

Table 2 EDX data of cadmium cobaltite

Element	Series	Weight %	Atomic %
Cadmium	L	24.17	8.46
Cobalt	K	52.96	35.34
Oxygen	K	22.87	56.21
Total		100.00	100.00

3.4 UV–VIS-NIR Spectroscopy Analysis

Using diffuse reflectance spectroscopy, one may determine the band gap of $CdCo_2O_4$, showing broad absorption (200–800 nm) with peaks at 226, 272, 379, and 566 nm. This range makes it an efficient visible light photocatalyst. The band gap (2.58 eV) is determined using the direct transition equation and Tau's plot as illustrated in Fig. 6.

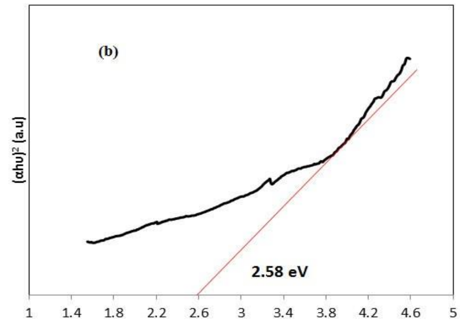

Fig. 6 Plot of $(\alpha h\nu)^2$ versus photon energy ($h\nu$) for the $CdCo_2O_4$

3.5 Typical Run

The formula used to get the rate constant is K = 2.303 × Slope. Fig. 7 shows a graphic representation of a typical run with a rate constant of 1.53×10^{-4} s^{-1}. Light intensity = 30.0 mW/cm^2, pH = 9.0, [Evan's blue] = 0.3×10^{-4} M, Semiconductor = 0.10 g.

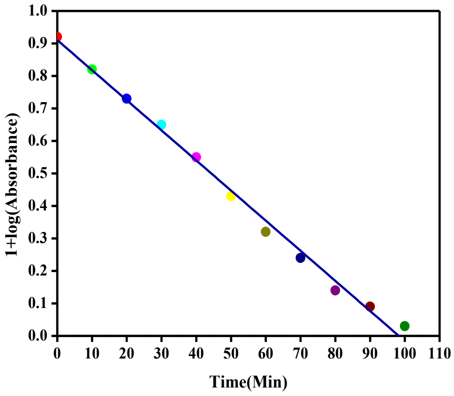

Fig. 7 Graph of typical run

3.5.1 Impact of the Parameters

3.5.1.1 Variations in pH

The range of 6.0 to 10.5 was used to examine the effects of pH change. The degradation rate was shown to rise with increasing pH up to 9.0, after which it was found to decrease. Dissolved oxygen absorbs an electron from the conduction band, producing $O_2^{\bullet}$ radicals. The higher pH-related increase in dye degradation rate could be attributed to these radicals' increased availability. However, the decreased rate of deterioration at higher pH values might result from the anionic form of Evan's blue, whose negatively charged semiconductor surface is repelled as shown in Fig. 8a due to the increased absorption of OH ions on the photocatalyst surface. The light intensity was 30.0 mW/cm^2, the semiconductor was 0.10 g and the [Evan's blue] was 0.3×10^{-4} M.

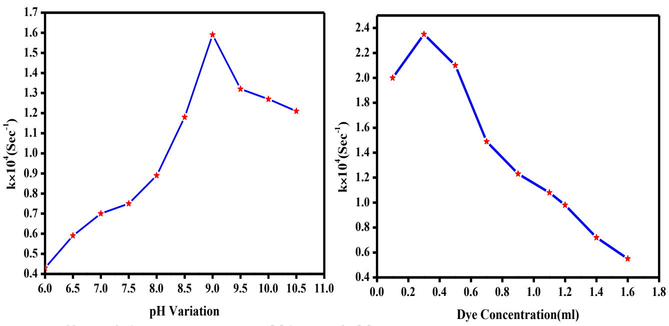

Fig. 8 Effect of a) pH variation and b) Evan's blue concentration

3.5.1.2 Effect of Evan's Blue Concentration

Fig. 8b presents the results of a study that was done between 0.1×10^{-4} and 1.8×10^{-4} M to examine the effect of dye concentration on the photocatalytic degradation of Evan's blue. Higher dye concentrations were shown to result in faster rates of degradation until an ideal concentration of 0.3×10^{-4} M was reached. The degrading efficiency dropped after this. This drop is the result of the dye's internal filtering activity, which prevents the desired light intensity from reaching the semiconductor surface at the bottom of the reaction vessel. pH = 9.0, semiconductor = 0.10 g, and light intensity = 30 mW/cm^2 were the parameters of the experiment.

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3.5.1.3 Effect of Catalytic Dosage of $CdCo_2O_4$

The concentration of the photocatalyst $CdCo_2O_4$ affects how quickly EB degrades by photocatalysis. The amounts of catalyst ranged from 0.02 g to 0.22 g. It was found that, up to a certain point, the catalyst amount increases the rate of EB photo-degradation until it reaches a maximum. Beyond this level, further increases in the catalyst amount result in a decrease in the degradation rate and these results are presented in Fig. 9a.

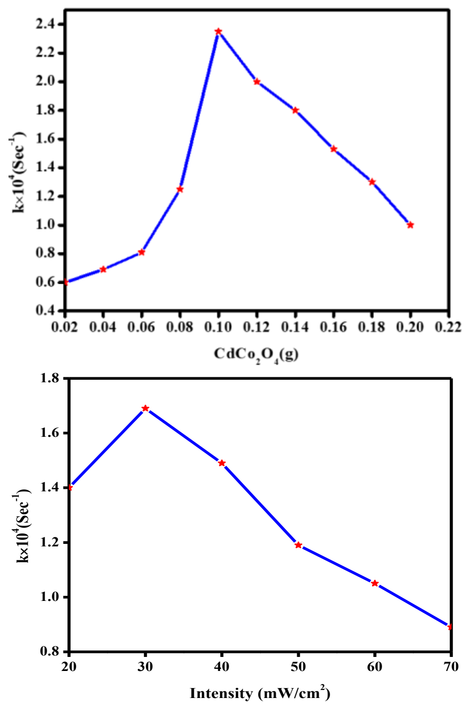

Fig. 9 Effect of a) catalytic dosage of $CdCo_2O_4$ and b) light intensity

3.5.1.4 Effect of Light Intensity

Additionally, it looked into how light intensity affected Evan's blue dye's photocatalytic breakdown. A range of 20 to 70 mW/cm^2 was found in the light intensity measurement between the exposed surface area of cadmium cobaltite and the light source. The results are shown in Fig. 9b. It was discovered that increasing light intensity enhanced the photocatalytic breakdown of Evan's blue. Higher light intensities cause more photons to strike the surface of the cadmium cobaltite photocatalyst per unit area per unit of time. However, a slight drop in the dye photo-degradation rate was noted when the light intensity rose above 30 mW/cm^2.

3.6 Mechanism

Evan's blue deterioration in the presence of cadmium cobaltite nanoparticles has been suggested as a possible mechanism based on experiment results. Intersystem crossover (ISC) is the process by which Evan's blue changes from a singlet excited state to a triplet excited state when sufficient light is absorbed. Khalid et al. [15,16] explained as when a semiconductor absorbs light, it also excites an electron from its valence band (VB) to its conduction band (CB), $O_2^{\bullet-}$ is then produced (in basic media) when it is absorbed by dissolved oxygen. Because of their ability to degrade dye to its leuco form, these radicals can create products.

$$EB_0 \xrightarrow{h\nu} EB_1 \quad (1)$$

$$EB_0 \xrightarrow{ISC} EB_1 \quad (2)$$

$$CdCo_2O_4\ NPs + e^- \xrightarrow{h\nu} CdCo_2O_4\ NPs\ h^+ (VB) + e^- (CB) \quad (3)$$

$$O_2\ (\text{Dissolved Oxygen}) + e^-(CB) \longrightarrow O_2^- \quad (4)$$

In basic medium,

$$EB_1 + O_2^- \xrightarrow{ISC} \text{Leuco EB} \quad (5)$$

$$\text{Leuco EB} \longrightarrow \text{Products} \quad (6)$$

3.7 Investigation of Potential Scavenging Mechanisms for the Breakdown of Evan's Blue Dye

It is crucial to determine the reactive species involved in Evan's blue dye solution's photocatalytic degradation to comprehend the mechanism. Sarita et al. [17] explained in their previous studies which have indicated that the major and secondary reactive species needed for this reaction, when using $CdCo_2O_4$ nanoparticles (NPs), are hydroxyl radicals ($^{\bullet}OH$) and oxygen radicals ($^{\bullet}O_2^-$). Research on scavenging was carried out utilizing:

The $^{\bullet}OH$ radicals can be eliminated with 10 mM of isopropyl alcohol (IPA). The photo-generated holes (h^+) can be eliminated with 10 mM of sodium oxalate. The $O_2^{-\bullet}$ free radicals can be eliminated with 10 mM of benzoquinone ($C_6H_4O_2$).

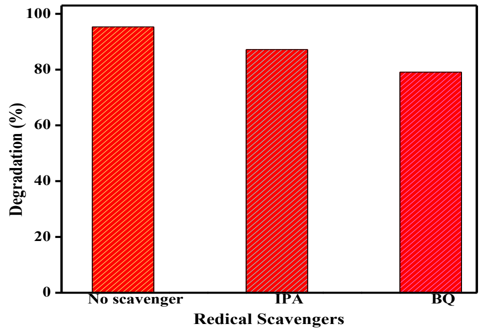

Fig. 10 Variations in quenchers' effects on Evan's blue degradation

Before the photocatalytic reaction, these scavengers were added to a catalyst-dye solution (40 mg/50 mL). The findings, which are depicted in Fig. 10 which reveals that the addition of IPA decreased photocatalytic degradation, indicating that ^-OH radicals were the main reactive species. Adding benzoquinone also reduced degradation, while EDTA had minimal effect, indicating that photo-generated holes do not play a significant role. To degrade Evans Blue using $CdCo_2O_4$ nanoparticles, the following photocatalytic process is suggested:

$$CdCo_2O_4 \xrightarrow{h\nu} h^+ (VB) + e^-(CB)$$

$$e^- + O_2 \longrightarrow {}^{\bullet}O_2^-$$

$${}^{\bullet}O_2^- + H^+ \longrightarrow H_2O$$

$$2H_2O^- \longrightarrow H_2O_2 + O_2$$

$$H_2O_2 + {}^{\bullet}O_2^- \longrightarrow OH^{\bullet} + OH^- + O_2$$

3.8 Cadmium Cobaltite's Reusability and Stability

To assess the reusability of the material, four distinct photocatalytic assays were conducted using recycled cadmium cobaltite photocatalyst added to freshly made solutions of Evan's blue. During these four cycles, the deteriorating activity of the cadmium cobaltite particles was noted. Using the same batch of cadmium cobaltite catalyst, repeated tests of Evan's blue degradation were undertaken to verify the stability and reusability of $CdCo_2O_4$. Evan's blue had a degrading efficiency of 96% in the first run and 72% by the fourth, as shown in Fig. 11. This modest drop in efficiency suggests that $CdCo_2O_4$ produced is a good catalyst for real-world uses.

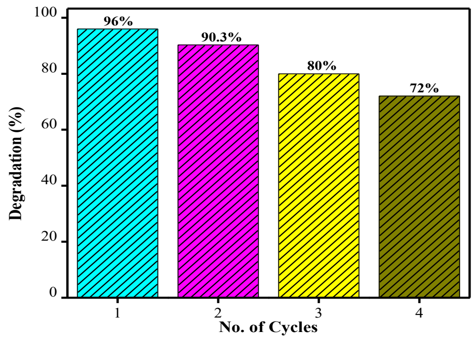

Fig. 11 Stability and reusability of cadmium cobaltite

4. Conclusion

This present study reports the successful synthesis of cadmium cobaltite via a simple and scalable wet chemical precipitation method and confirms its effectiveness as a visible-light-responsive photocatalyst. Under optimized alkaline conditions, the photocatalyst achieved approximately 96% degradation of Evans blue dye and followed pseudo-first-order kinetics. The enhanced activity is attributed to improved visible-light absorption and suppressed electron–hole recombination, leading to efficient reactive oxygen species generation. Moreover, the catalyst exhibited good stability and reusability, demonstrating its potential for sustainable wastewater treatment applications.

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References

[1] C.J. Cooksey, Quirks of dye nomenclature, 1. Evans blue, Biotech. Histochem. 89(2) (2014) 111-113.

[2] C.J. Cooksey, Quirks of dye nomenclature, 3. Trypan blue, Biotech. Histochem. 89(8) (2014) 564-567.

[3] C.J. Cooksey, Quirks of dye nomenclature, 8. Methylene blue, azure and violet, Biotech. Histochem. 92(5) (2017) 347-356.

[4] R. Gelmini, M. Campanelli, F. Cabry, A. Franceschetto, G. Ceresini, L. Ruffini, P. Del Rio, Role of sentinel node in differentiated thyroid cancer: a prospective study comparing patent blue injection technique, lymphoscintigraphy and the combined technique, J. Endocrinol. Invest. 41 (2018) 363-370.

[5] K.J. Kumara, G. Krishnamurthy, N.S. Kumar, N. Naik, T.M. Praveen, Sustainable synthesis of magnetically separable SiO_2/Co@ Fe_2O_4 nanocomposite and its catalytic applications for the benzimidazole synthesis, J. Magn. Magn. Mater. 451 (2018) 808-821.

[6] K.S. Jithendra Kumara, G. Krishnamurthy, B.E. Kumara Swamy, N. Sunil Kumar, M. Kumar, Catalytic performance study of nano-cobalt: a catalyst for complement to the Heck coupling reaction, J. Porous Mater. 24(4) (2017) 1095-1103.

[7] K.S. Jithendra Kumara, G. Krishnamurthy, B.E. Kumara Swamy, N.D. Shashi Kumar, Satish Naik, B.S. Krishna, Nagaraj Naik, Terephthalic acid derived ligand-stabilized palladium nanocomposite catalyst for Heck coupling reaction: without surface-modified heterogeneous catalyst, Appl. Organomet. Chem. 31(1) (2017) e3549.

[8] M.B. Tahir, M. Sagir, Carbon nanodots and rare metals (RM= La, Gd, Er) doped tungsten oxide nanostructures for photocatalytic dyes degradation and hydrogen production, Sep. Purif. Technol. 209 (2019) 94-102.

[9] J.R. Adarsha, T.N. Ravishankar, C.R. Manjunatha, T. Ramakrishnappa, Green synthesis of nanostructured calcium ferrite particles and its application to photocatalytic degradation of Evans blue dye, Mater. Today Proc. 49 (2022) 777-788.

[10] K.R. Sumadevi, G. Krishnamurthy, P. Walmik, R.P. Rani, S. Naik, H.B. Naik, N. Naik, Photocatalytic degradation of Eriochrome black-T and Evan's blue dyes under the visible light using PVA capped and uncapped Ag doped ZnS nanoparticles, Emerg. Mater. 4 (2021) 447-456.

[11] R.E. Adam, Synthesis and characterization of some nanostructured materials for visible light-driven photo processes, Vol. 2059, LiU E-Press, Sweden, 2020.

[12] X. Wei, D. Chen, W. Tang, Preparation and characterization of the spinel oxide $ZnCo_2O_4$ obtained by sol–gel method, Mater. Chem. Phys. 103(1) (2007) 54-58.

[13] X.H. Xia, J.P. Tu, Y.J. Mai, X.L. Wang, C.d. Gu, X.b. Zhao, Self-supported hydrothermal synthesized hollow Co_3O_4 nanowire arrays with high supercapacitor capacitance, J. Mater. Chem. 21(25) (2011) 9319-9325.

[14] K. Kaviyarasu, C.M. Magdalane, K. Anand, E. Manikandan, M. Maaza, Synthesis and characterization studies of MgO: CuO nanocrystals by wet-chemical method, Spectrochim. Acta A Mol. Biomol. Spectrosc. 142 (2015) 405-409.

[15] N.R. Khalid, A. Arshad, M.B. Tahir, M.K. Hussain, Fabrication of p–n heterojunction Ag_2O@Ce_2O nanocomposites make enables to improve photocatalytic activity under visible light, Appl. Nanosci. 11 (2021) 199-206.

[16] N.R. Khalid, M.K. Hussain, G. Murtaza, M. Ikram, M. Ahmad, A. Hammad, A novel Ag_2O/Fe–TiO_2 photocatalyst for CO_2 conversion into methane under visible light, J. Inorg. Organomet. Polym. Mater. 29 (2019) 1288-1296.

[17] Sarita, S. Sharma, A.S. Kumawat, K. Intodia, Photocatalytic degradation of new fuchsine using lead chromate for water reuse: Efficiency and degradation pathway contaminants remediation, Orient. J. Chem. 40(4) (2024) 1183-1188.

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