Short Communication:

Photo-Decolorization of Eosin Yellow Dye Using Oxidants of $K_2S_2O_8$ and H_2O_2 Catalyzed with ZnS Nanoparticles

Faten Hadi Fakhri[1*], Thaqeef Murtada Jawad[2], Haithem Fadhil Abdulhasan[3], Luma Majeed Ahmed[3,4], Afrah Majeed Ahmed[5], Raja Khedir Mohammad[6], Eussur Noori Alkhafaji[3], Maryam Amoori Jasim[1], Jalal Jameel Jahil[3], and Ali Raheem Abbas[3]**

[1]*Presidency University of Kerbala, Karbala 56001, Iraq*

[2]*Department of Chemistry, College of Science, University of Wasit, Al-Kut, Wasit 52001, Iraq*

[3]*Department of Chemistry, College of Science, University of Kerbala, Karbala 56001, Iraq*

[4]*Al-Zahraa Center for Medical and Pharmaceutical Research Sciences (ZCMRS), Al-Zahraa University for Women, Karbala 56001, Iraq*

[5]*Department of Anesthesia Techniques College of Health and Medical Technologies, Almustakbal University, Babylon 51001, Iraq*

[6]*Department of Physics, College of Science, University of Kerbala, Karbala 56001, Iraq*

* ***Corresponding author:***

email: faten.h@uokerbala.edu.iq; luma.ahmed@uokerbala.edu.iq***

Received: October 3, 2025
Accepted: November 23, 2025

DOI: 10.22146/ijc.111766

Abstract: *The effect of $K_2S_2O_8$ and H_2O_2 as oxidation agents was examined on the removal and photo-decolorization of eosin yellow dye, which was catalyzed by ZnS-NP. The photoreactions were performed under an artificial UV-A lamp and solar irradiation at 20 and 40 °C respectively. At the dark reaction, the increase in temperature from 20 to 40 °C leads to an increase in the resistance to the dye removal in the presence of the oxidant agents. The dye's photodecolorization without oxidant agents gives a maximum decolorization efficiency with solar irradiation. Because of this dye is colored aromatic dye, thus its directly affected with the visible reign of the solar spectrum. Maximum photodecolorization efficiency and quantum yield were found at 99.314% and 2.91 when the addition of H_2O_2 to the ZnS-NP/eosin yellow/UV-light system. In contrast, the addition of $K_2S_2O_8$ and H_2O_2 to the system under solar irradiation decreased the efficiency and quantum yield due to increasing the dye resistance to the decolorization process. The photoreaction obeys pseudo-first-order kinetic model. The mechanism of both systems was suggested, and the results found that ZnS-NPs could pave the way for practical applications in wastewater treatment.*

Keywords: *xanthene dye; removal; photocatalytic decolorization; quantum yield; nano ZnS-blended*

■ INTRODUCTION

Researchers of photochemistry is deemed as one of the most active fields that have contributed to advance the science from clean energy [1]. They discussed and treated various topics, as a solar cells [2], fluorescent chemo-sensors [3], chemical synthesis [4], adsorption [5], biosorption [6], Fenton, photo-Fenton and solar photo-Fenton [7-8] photoluminescent polymers [9], photochromic materials [10], solar photocatalysis [11], anti-microbial [12] and innovation and chemical industry [13-14]. Photochemistry has greatly extended to the red photo-catalyst absorbance, these photo-reactions, through the reaction of light, chemicals are produced under mild conditions similar to those in plants, provided the reactions are selective [15]. The photocatalysts such as ZnS, CuO, TiO_2, and CeO_2 are

regarded as a non-toxic and inexpensive materials that are actively used against a majority of sources of biological inhibitors, corrosion inhibitors, organic complexes like Schiff base complexes, organophosphorus pesticides, low-density polyethylene plastics and various organic wastewaters derived from textile dyes, such as xanthene dyes [16-17]. These dyes have a relatively low molecular mass, high fastness and brightness, no significant solubilizing groups, and are non-ionic compounds, such as eosin yellow disodium salt dye, which is classed as a xanthene dye (see Table 1) hence, they are slightly soluble in water [18].

ZnS has been recognized as a promising material for applications as heterogeneous photocatalysts that belongs to group II–VI as an n-type ionic semiconductor, which has two different crystal structure (wurtzite and blended) with different properties. ZnS-blended cubic structure form is more stable than wurtzite form, in addition to having a direct energy gap equal to 3.54 eV and due to its electronic structure, the ZnS-blended has can mostly be used in solar cells and in photocatalysis application [19]. The photo-enhanced process has illustrated to be extremely efficient and is suitable for eliminating the residual traces of contaminants after pre-treatment with hydrogen peroxide, Fenton or other oxidant reagents, which is dependent on the wavelength of the radiation and the photocatalyst effectiveness and the energy difference between the valence band (VB) and the conduction band (CB) of the used photocatalyst [20]. Despite of the effect of anions is various and difficult to predict, potassium persulfate ($K_2S_2O_8$) and hydrogen peroxide (H_2O_2) could enhance the ZnS catalyzed photo-reaction rate by photocatalysis and the effect of adsorption on the surface of ZnS gave a strong power of oxidizing/reducing effect of the (h^+/e^-) that generated at the surface of ZnS in a photochemically process [21-22]. Wastewater contains not only organic pollutants but also a large number of inorganic anions such as NO_3^-, SO_4^{2-}, and CO_3^{2-} [23]. So, it is useful to study the influence of these ions on this photocatalytic process. These ions could possibly have the inhibitory effect on the photocatalyst activity or have the changing effect of the ionic strength of the reaction medium [24]. This work aims to investigate the dark reaction for removal of eosin yellow dye using nano ZnS at 20 and 40 °C. Moreover, the photocatalytic activity will perform using nano ZnS to decolorize of eosin yellow dye under UV-A light at 20 °C and under solar light at 40 °C. The removal and photo-decolorization will study without and with using oxidant agents such as the $K_2S_2O_8$ and the H_2O_2. The quantum yield will estimate for photoreaction under UV-A and solar light.

■ EXPERIMENTAL SECTION

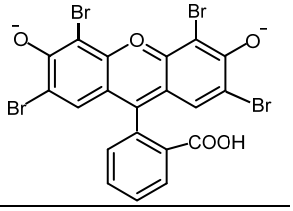
Materials

All of the chemical reagents that used in experiments of this work were in analytical grade (Fluka) and utilized without any purification begins from the nano ZnS catalyst with crystal size of 40.4018 nm, $K_2S_2O_8$, and 30% H_2O_2. Eosin Y disodium salt dye provided by Hilla textile factory and the general properties are shown in Table 1.

Instrumentation

Fourier transform-infrared (FTIR) spectrum was recorded using KBr discs with the FTIR-8400S Shimadzu covering the range of 4000 to 400 cm^{-1}. The concentration of residue dye was analyzed using a double beam ultraviolet-visible (UV-vis) spectrophotometer, Shimadzu (AA-1800 Japan). The photo-application method was applied with using a high-pressure mercury lamp, Cnlight (ZW15S 15 W-Z436, China). Centrifuge

Table 1. General properties of eosin Y disodium salt dye

Dye name	Eosin Y disodium salt
Dye no.	E6003
Dye class	Xanthene dye
Formula	$C_{20}H_6Br_4Na_2O_5$
Molar mass g/mol	691.85
Color of powder	Brown
λ_{max}	516 nm
Structure	

(Hettich- Universal II- Germany) was employed for samples separation from catalyst solution and hotplate stirrer type (Heido-MrHei-Standard, Germany) was utilized during mixing the solutions. Moreover, the photo-reactor homemade Instrumentation was demonstrated in Fig. 1 to perform the photocatalytic experiments. The dark reaction was done as system B, which regarded as a synergistic step for performing the steps A and C in photoreaction systems. The A and C systems consist of source of light (15 W) with light intensity 9.14×10^{-8} Einstein/s that calculated using reference [25], and in solar reaction system (system C) the light intensity of solar light in presence a lens was found to be 5.40×10^{-8} Einstein/s during August 2022 at 40 °C. In system A, the wooden box that wrapped with foil of aluminum was used to raise the absorbance capacity of UV radiation.

Procedure

Applications of the removal of eosin Y dye

The dark reaction calculations (as in Fig. 1) were performed on the mixture solution of 100 mL of 10 ppm eosin Y dye in the presence of nano ZnS as a photo-catalyst, with/without oxidant agents (H_2O_2 and $K_2S_2O_8$). These solutions are mixed for 30 min to reach for the best contact time, which ensures to occupy most of the active sites of the nano ZnS catalyst that is immersed in the studied dye solution [26-27]. Approximately 3 mL of colloidal solution was recovered and filtered. The absorbance of the generated filtered solution was measured at 516 nm to calculate the concentration using a previously assembled calibration curve. The adsorption capacities q_e (mg/g) for 30 min was calculated by using Eq. (1) [28-29];

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

where m is the mass in g for dry adsorbent (nano ZnS) used, C_0 and C_e or are the initial and equilibrium dye concentrations in solution, V is the volume of adsorbate (dye) in L. The percentage of adsorption (removal) efficiency ($E_{removal}$%) of eosin y dye can be obtained from equation (2) [30–32].

$$E_{removal}\,\% = \frac{(C_0 - C_e)}{C_0} \times 100\% \quad (2)$$

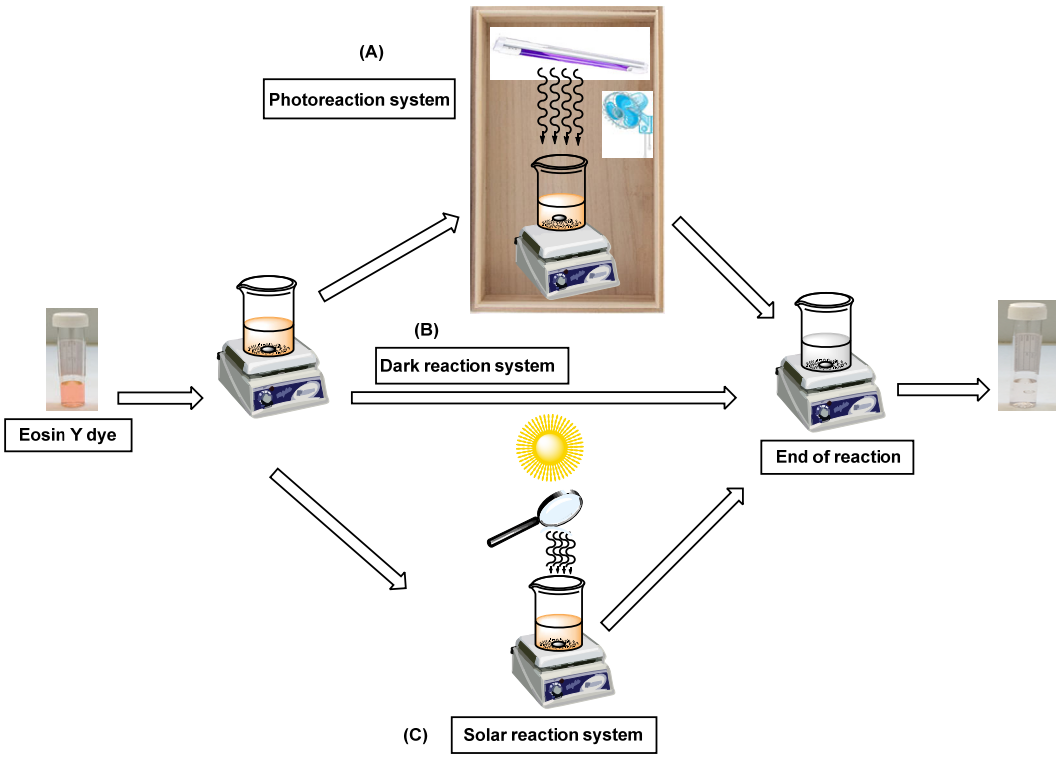


Fig 1. Photo-reactor setup for the two systems

The adsorption process alone is insufficient to remove eosin yellow dye in 30 min as an equilibrium time, so the photo reaction must be used as the next step to decolorize it. After 30 min. of a dark reaction, the photo reaction was carried out by switching on the UV-A or solar light to the mixed solution. At various times of irradiation by UV-A/solar light, about 3 mL of the exposed solution was transferred to a plastic test tube and doubly centrifuged for 15 min. At the same wavelength (516 nm), the residual concentration of the dye was measured. To calculate the apparent rate constant (k_{app}) for this photo reaction, Eq. (3) is employed [33-34];

$$\ln\left(\frac{C_0}{C_t}\right) = k_{app}t \quad (3)$$

where C_0 is an initial concentration of dye without irradiation (after 30 min from dark reaction) and C_t is a concentration of the same studied dye at t time of illumination. The %efficiency of decolorization (E_{decol}%) for dye was conducted using Eq. (4) [33,35].

$$E_{decol}\,\% = \frac{(C_0 - C_t)}{C_0} \times 100\% \quad (4)$$

The quantum yield φ was calculated [36-37] depended on k_{app} and light intensity for UV-A and solar light as shown in Eq. (5) and (6);

$$\varphi = \frac{\text{no. of molecules decomposed}}{\text{no. of photons of light adsorbed}} \quad (5)$$

$$\varphi = \frac{k_{app}}{2.303 I_0 \varepsilon_\lambda l} \quad (6)$$

where k_{app} is the rate constant of dye in min^{-1} at photo-decolorization with light source, I_0 is the incident light intensity that is calculated for UV-A and solar light, l is the cell length in cm and ε_λ is the molar absorptivity of Eosin yellow dye (3558 L mol^{-1} cm^{-1}).

■ RESULTS AND DISCUSSION

Effect of Oxidant Agents on Dark Reaction

The experiment's dark reactions were performed in Fig. 2, which added 0.5 g of nano ZnS in the aqueous solution of 10 ppm Eosin yellow dye at pH equal to 7.7 for 30 min. The $E_{removal}$% is found to be 75.037 and 82.9123% at 20 and 40 °C, respectively. This result enhances the movement of the dye molecules toward the active site and adsorption with increasing the temperature. While the addition of $K_2S_2O_8$ as an oxidant agent alters the removal efficiency to 76.225 and 67.756% at 20 and 40 °C, respectively, that attributed to the cleavage the oxidant agents $K_2S_2O_8$ then adsorption on ZnS surface and reaction with adsorbed water to degrade the dye by

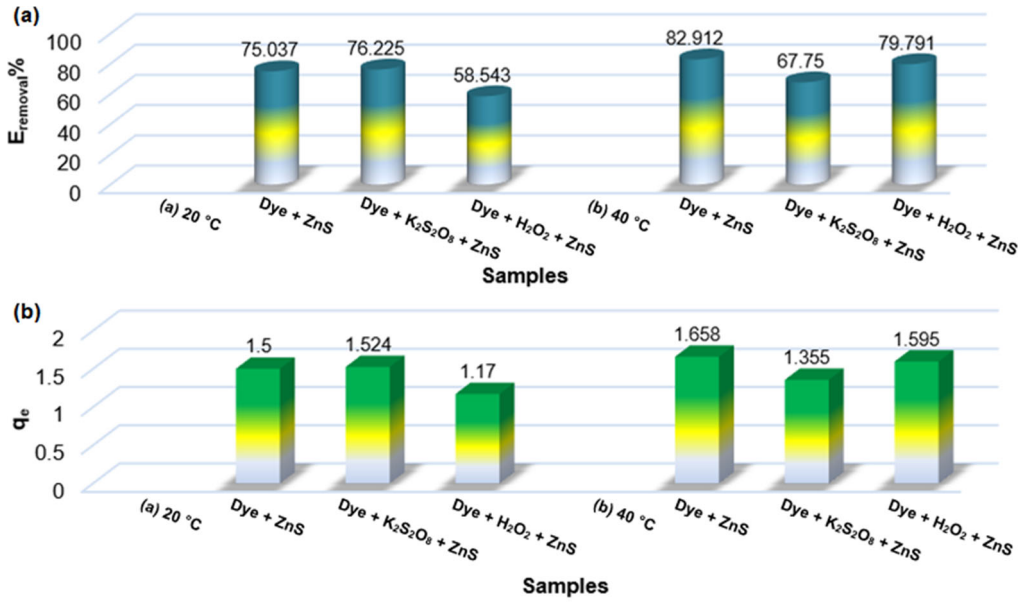


Fig 2. The (a) $E_{removal}$% and (b) q_e for dark reaction for eosin Y/nano ZnS and eosin Y/oxidant agents ($K_2S_2O_8$ and H_2O_2)/nano ZnS systems at 20 and 40 °C

hydroxyl and peroxide radical species, [38-39], but the depress in efficiency at 40 °C can be attitude to couple the radicals and dissolve the nano ZnS as a Zn^{2+} ions (see Eqs. (7–9)).

$$S_2O_8^{2-} \rightarrow 2SO_4^{-} \quad (7)$$

$$SO_4^{-} + H_2O \rightarrow OH^{\bullet} + HSO_4^{-} \quad (8)$$

$$ZnS + 3OH^{\bullet} \rightarrow Zn^{2+} + S^{2-} + HOO^{\bullet} + H_2O \quad (9)$$

The adsorption capacity (q_e) for this reaction in the presence of H_2O_2 is clearly decreased at 20 °C, from 1.5 to 1.17 mg/g, that due to adsorption the H_2O_2 molecule on nano ZnS surface and comparative with the dye molecules linked in active site. At 40 °C, the decreased in adsorption capacity is very low from 1.65 to 1.595 mg/g that ensure the evaporated of most H_2O_2 molecule.

Effect of Oxidant Agents on Photo-Reaction

A series of photoreaction experiments was applied with the addition of 0.5 g of nano ZnS in an aqueous solution of 10 ppm eosin yellow dye at pH equal to 7.7, without and with oxidant agents under UV-A at 20 °C and solar light at 40 °C. Based on Fig. 3, the photoreaction for all samples is linear and obeys pseudo-first-order [40]. The photoreaction using solar is fast at 40 °C, which is due to an endothermic reaction [41-42]. At 40 °C, the maximum E_{decol}% of solar reaction in Fig. 4, demonstrates at 92.293%, which decreases to 82.675 and 78.398% with using K_2S_2O8 and H_2O_2 as oxidant agents, respectively. This case obtains increased in movement of hydroxyl radical that produced from cleavage of H_2O_2, which work as trap by allowing it to react together and produced water molecules [43-44]. The addition of $K_2S_2O_8$ also decreases efficiency at 40 °C, which leads to an increase in the formation of hydroxyl radicals that also react together and depress the efficiency [45].

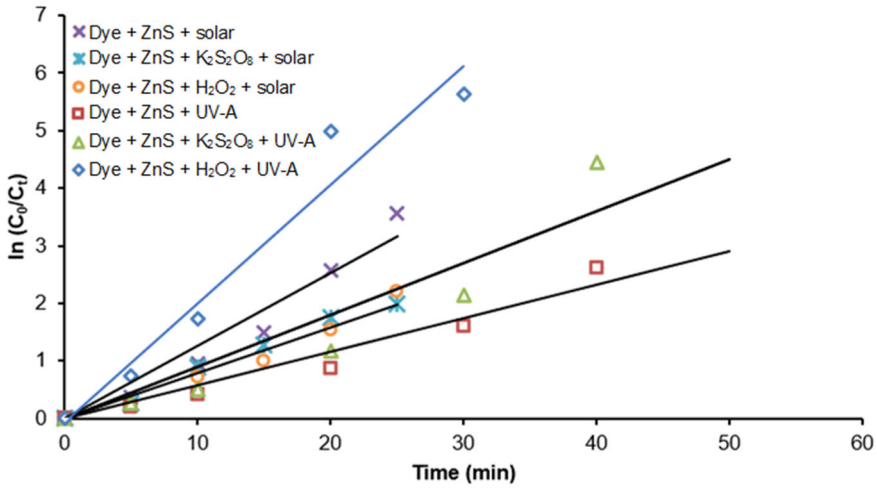


Fig 3. Photoreaction of eosin yellow for eosin Y/catalyst and eosin Y/oxidant agents ($K_2S_2O_8$ and H_2O_2)/nano ZnS systems

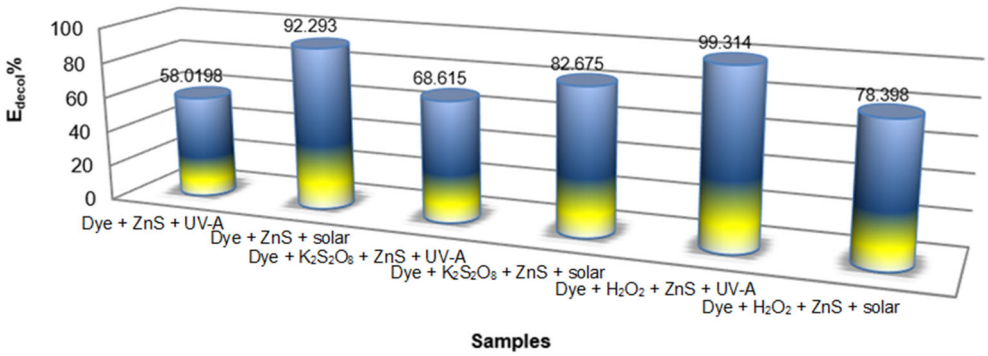


Fig 4. E_{decol}% of photo reaction for eosin Y/nano ZnS and eosin Y/oxidant agents($K_2S_2O_8$ and H_2O_2)/nano ZnS systems

From the other side, at 20 °C, the efficiency of this reaction increases after adding $K_2S_2O_8$ and H_2O_2 from 58.019 to 68.615 and 99.314%, respectively, which ensure the high activity for both to generate a hydroxyl radical in percent UV-A light (see Fig. 4). That because the photo-induced solution reaction of H_2O_2 would be occur with the utilized UV-A. This behavior indicates variations in the oxidative strength of the oxidizing reagent used, which leads to their degradation as shown in Eqs. (10–13) [39,46-47].

$$ZnS + h\nu \rightarrow h^+_{vb} + e^-_{cb} \quad (10)$$

$$H_2O_2 + h\nu \rightarrow 2HO^\bullet \quad (11)$$

$$H_2O_2 + e^-_{cb} \rightarrow OH^\bullet + HO^- \quad (12)$$

$$HO^- + h^+_{vb} \rightarrow HO^\bullet \quad (13)$$

The exposing of $K_2S_2O_8$ to UV light leads to photolysis, which will generate additional SO_4^- according to the reaction's photolysis [36,39,48] (see Eq. (10) and (14–16).

$$S_2O_8^{2-} + h\nu \rightarrow 2SO_4^{-\bullet} \quad (14)$$

$$S_2O_8^{2-} + e^-_{cb} \rightarrow SO_4^{-\bullet} + SO_4^{2-} \quad (15)$$

$$SO_4^{-\bullet} + H_2O \rightarrow SO_4^{-2} + HO^\bullet + H^+ \quad (16)$$

The Quantum Yield (φ) and Photo-Decolorization of Eosin Y Dye

Eosin Y dye decolorized by the exposure of UV-A and solar light using 0.5 g of the catalyst nano ZnS in natural (pH = 7.7). Fig. 5 displays the quantum yield values with various oxidant agents. The quantum yield efficiency ranged from 0.830 to 2.912, showing good results. The quantum yield for decolorization of eosin y dye with nano ZnS presence's solar light were 2.619, followed by a decreasing in quantum yields to 1.720 and 1.644 when used $K_2S_2O_8$ and H_2O_2 respectively. This is attributed to the fact that not all UV-A or solar light is absorbed in the photocatalytic solution by the eosin y in the presence of the photocatalyst ZnS, but rather a portion of the light is absorbed, transmitted or scattered, as the quantum factor is a sensitive parameter to investigate the photocatalytic reaction [36,49]. While the quantum yield for decolorization of eosin Y dye with the presence of nano ZnS under UV-A light was 0.830, the quantum yield increased to 1.287 with the addition of $K_2S_2O_8$. Whereas the photo-reaction obtained φ = 2.912 with using peroxides. The use of some inorganic oxidizing agents in photonic systems like $K_2S_2O_8$ and H_2O_2 in (solar light or UV-light/nano ZnS) system could be increase the quantum yield efficiencies by inhibiting the recombination of the (h^+/e^-) pair through interaction with the conduction band electrons on the nano ZnS surface or by introducing an additional oxygen atom as an electron acceptor to form the super- oxide radical ions [50-51].

Mechanism of Photo Decolorization of Eosin Yellow Dye

Photocatalytic reactions rely on the presence of active species such as superoxide anion, peroxide radical, and hydroxyl radical in solution or on the photocatalyst surface in the presence of artificial lamp or solar radiation. These species have the capacity to decolorize and destroy the organic-colored materials. In aqueous solutions, hydroxyl radicals are more active and function as a potent oxidant, attacking color molecules [52-53]. Fig. 6 shows the proposed eosin yellow decolorization [54].

Mechanism of Dark Reaction and Photo-Decolorization of Eosin Yellow Dye

The dark reaction is deemed as a synergistic step to photoreaction according to the Langmuir-Hinshelwood (L-H) model [6,60]. Based on Fig. 7, the suggested

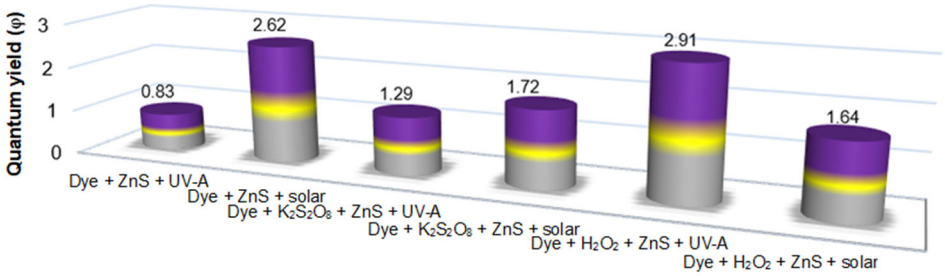


Fig 5. Quantum yields of eosin Y/nano ZnS and eosin Y/oxidant agents ($K_2S_2O_8$ and H_2O_2)/nano ZnS systems

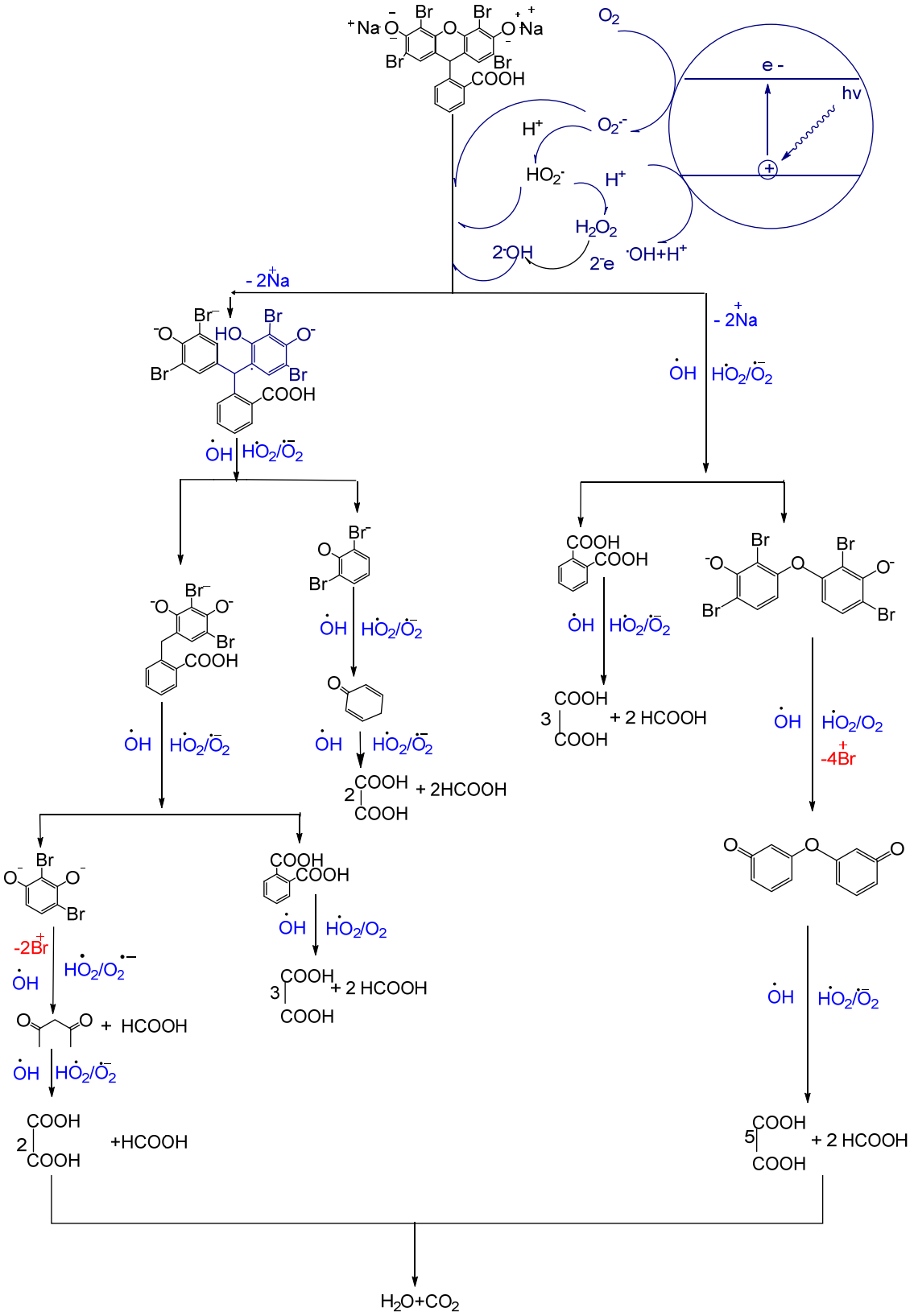


Fig 6. Suggested the photo-decolorization mechanism of eosin yellow dye

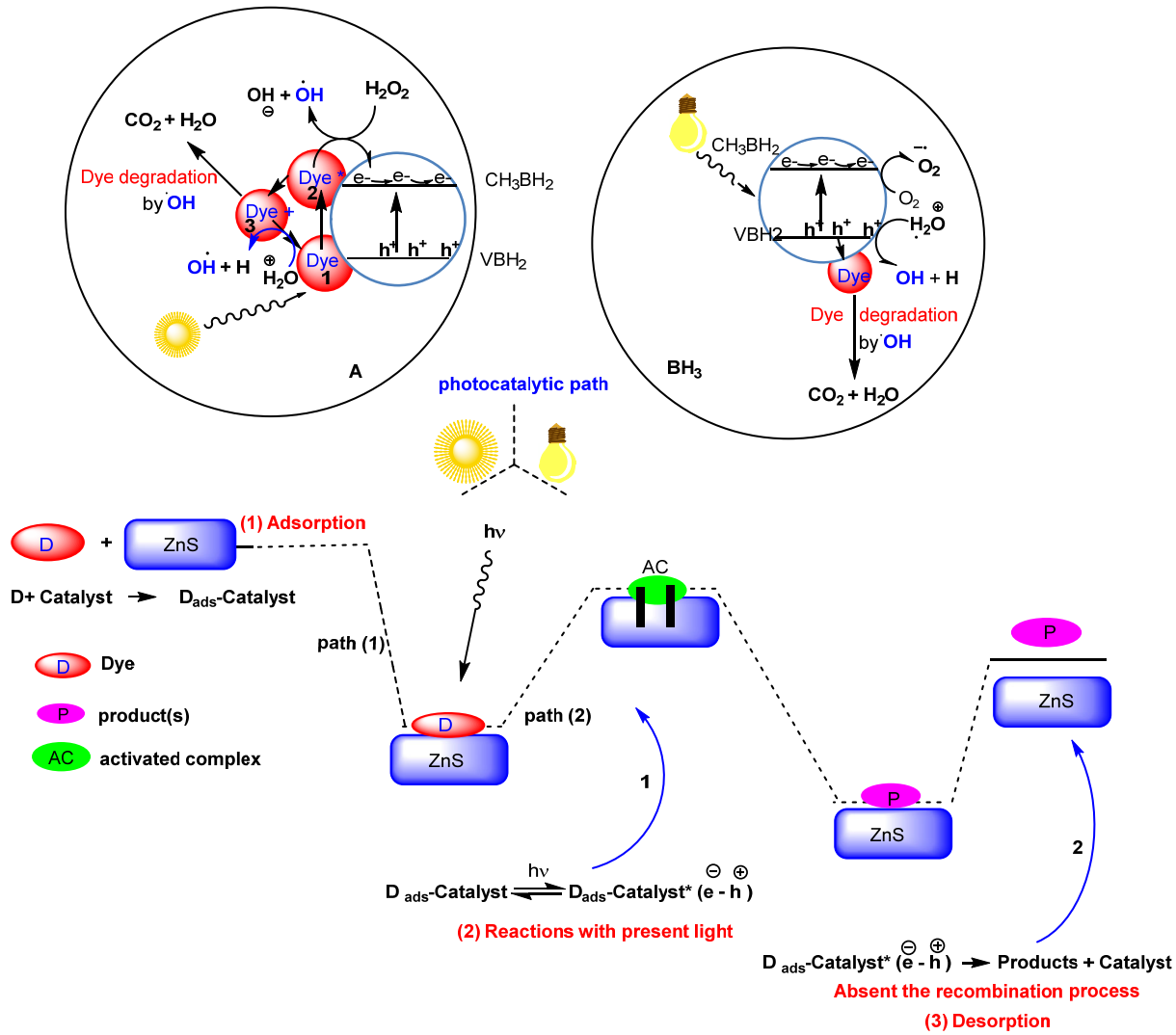


Fig 7. Schematic diagram of adsorption and photo-process paths on the surface of catalyst (ZnS NP) under (a) solar light and (b) UV-A light

mechanism for the photoreaction lab system or solar reaction is done after the adsorption path and leads to produce desorption products as small active species. The photocatalytic path divides into path A, which happens in the presence of solar light, which focuses on the catalyst and dye because solar radiation includes three regions: UV, visible, and part of the near IR spectrum, hence solar light can cause photo and thermal reactions at the same time. While the path B is depending on using the artificial UV-A light (HPML-365 nm) that fills on catalyst directly and activation it to work as an electro-photocell. Both paths can be formed by photoelectrons and photo-holes, which are essential to start the photoreaction.

■ CONCLUSION

In this study, a series of photo and dark experiments were conducted to achieve the photo decolorization and adsorption reaction of 10 ppm of eosin yellow dye solution with 0.5 g of nano ZnS. The photo experiments were performed using a handmade photo-reactor equipped with a 15-W UV lamp at 20 °C and direct solar light at 40 °C. In the dark reaction, the addition of H_2O_2 at 20 °C decreases the removal efficiency, but at 40 °C the removal is slight. The photo decolorization of eosin yellow dye solution was done under controlled conditions without and with the addition of oxidant agents like H_2O_2 and $K_2S_2O_8$.

Moreover, it's found that the best decolorization under UV-A light occurs with the addition H_2O_2, but the best decolorization of the same dye under solar light alone. The quantum yield refers to the active about 1-3 dye molecules under absorbed 1 mol from photons of UV-A light or solar light. For all these influences, the photoreaction obeys the pseudo-first-order. These results suggest that the development of ZnS-based photocatalysts as an efficient, low-cost, and environmentally friendly material for solar-powered pollutant analysis. They also suggested that improving photocatalyst properties could pave the way for practical applications in wastewater treatment and renewable energy systems.

■ ACKNOWLEDGMENTS

The authors would like to acknowledge University of Kerbala for their support and research facilities.

■ CONFLICT OF INTEREST

The authors declare no conflict of interest.

■ AUTHOR CONTRIBUTIONS

Luma Majeed Ahmed, Faten Hadi Fakhri and Thaqeef Murtada Jawad Conducted the experiments, performed data collection, and investigation. Luma Majeed Ahmed, Haithem Fadhil Abdulhasan, Afrah Majeed Ahmed, Raja Khedir Mohammad, Eussur Noori Alkhafaji Performed data analysis, formal analysis, and interpretation of the results. Faten Hadi Fakhri, Thaqeef Murtada Jawad, Luma Majeed Ahmed Wrote the original draft of the manuscript. Luma Majeed Ahmed, Maryam Amoori Jasim, Afrah Majeed Ahmed, Jalal Jameel Jahil, and Ali Raheem Abbas and Haithem Fadhil Abdulhasan Contributed to reviewing, editing, and final proofreading of the manuscript. All authors have read and agreed to the published version of the manuscript.

■ REFERENCES

[1] König, B., 2017, Photocatalysis in organic synthesis – Past, present, and future, *Eur. J. Org. Chem.*, 2017 (15), 1979–1981.

[2] Spanopoulos, I., Ke, W., and Kanatzidis, M.G., 2021, In quest of environmentally stable perovskite solar cells: A perspective, *Helv. Chim. Acta*, 104 (1), e2000173.

[3] Himshweta, H., Verma, N., Trehan, N., and Singh, M., 2025, Molecularly imprinted polymers-ZnS quantum dots based composite sensor for optical detection of chlorogenic acid, *Anal. Biochem.*, 702, 115846.

[4] Patel, A.R., Sahu, D.P., Rathore, S., and Gupta, N., 2025, Facile synthesis of PVA-supported ZnS nano-cottons as recyclable catalyst for the efficient reduction of *p*-nitrophenol and photodegradation of solochrome dark blue under the sunlight irradiation, *Discover Catal.*, 2 (1), 2.

[5] Maatoq, S.L., and Ali, I.H., 2025, Green fabrication of silica with zinc oxide as nanocomposite for adsorption of methylene blue dye from aqueous solution, *Indones. J. Chem.*, 25 (5), 1451–1461.

[6] Zorgani, M.A., Zaoui, F., Zorgani, R.N.E.H., Elhadj Daouadji, B., Sebba, F.Z., Choukchou-Braham, E., Bounaceur, B., Ma, Y., Bhardwaj, M., and Ma, H., 2024, Ultrasonic-assisted adsorption of heavy copper and lead metal ions by g-C_3N_4, application of g-C_3N_4@MNPs (M: Pb, Cu) in the catalytic photoreduction of organic pollutants, *J. Water Process Eng.*, 58, 104724.

[7] Pino-Sandoval, D.A., Cantú-Cárdenas, M.E., Rodríguez-González, V., Patrón-Soberano, O.A., Rosas-Castor, J.M., Murillo-Sierra, J.C., and Hernández-Ramírez, A., 2023, Solar heterogeneous photo-Fenton for complete inactivation of *Escherichia coli* and *Salmonella typhimurium* in secondary-treated wastewater effluent, *Chemosphere*, 342, 140132.

[8] Liu, L., Wang, L., Sun, D., Sun, X., Liu, L., Zhao, W., Tayebee, R., and Liu, B., 2023, ZnO-ZnS heterostructure as a potent photocatalyst in the preparation of some substituted chromenes and remarkable antigastrointestinal cancer activity, *ACS Omega*, 8 (46), 44276–44286.

[9] Dikmen, Z., 2024, Optically anisotropic films of colloidal nanocrystals/photoluminescent dye doped polymers, *Celal Bayar Univ. J. Sci.*, 20 (1), 16–22.

[10] Li, L., Yu, Y.T., Zhang, N.N., Li, S.H., Zeng, J.G., Hua, Y., and Zhang, H., 2024, Polyoxometalate (POM)-based crystalline hybrid photochromic materials, *Coord. Chem. Rev.*, 500, 215526.

[11] Le, M.V., Tran, T.T., Hoang, A.H., Nguyen, H.T., Le, V.T.S., Luan, V.H., and Ngo, M.T., 2025, Solar-light-driven N-TiO_2-SiO_2 photocatalytic activity on the simultaneous removal of bisphenol-A and *Escherichia coli*, *Indones. J. Chem.*, 25 (2), 458–470.

[12] Mediavilla, M., Valencia, L.F., Quiroz-Vela, C.L., Zúñiga-Benítez, H., Villa, A.L., and Peñuela, G.A., 2025, Antimicrobial and photocatalytic potential of a composite of ZnO-ZnS and activated carbon obtained from banana peel, *Water, Air, Soil Pollut.*, 236 (9), 578.

[13] Zhang, Y., Su, A., Ding, Y., Wu, Y., Tan, Y., and Chang, J., 2025, Construction of hollow TiO_2/ZnS heterojunction photocatalysts for highly enhanced photodegradation of tetracycline hydrochloride, *Molecules*, 30 (17), 3644.

[14] Abass, S.K., Al-Hilfi, J.A., Abbas, S.K., and Ahmed, L.M., 2020, Preparation, characterization and study of the photodecolorization of mixed-ligand binuclear Co(II) complex of Schiff base by ZnO, *Indones. J. Chem.*, 20 (2), 404–412.

[15] Truong, V.T., Le, P.N.M., and Le, M.V., 2025, Influence of hydrothermal parameters on photocatalytic activity of $BiVO_4$ for degradation of methylene blue, *Indones. J. Chem.*, 25 (3), 744–759.

[16] Hariani, P.L., Salni, S., Kimur, M.V., Hidayati, N., and Elfita, E., 2025, Fabrication of $NiFe_2O_4$/SiO_2/TiO_2 magnetic composite for effective photodegradation of Congo red dye, *Indones. J. Chem.*, 25 (3), 665–679.

[17] Jawad, T.M., AL-Lami, M.R., Hasan, A.S., Al-Hilfi, J.A., Mohammad, R.K., and Ahmed, L.M., 2021, Synergistic effect of dark and photoreactions on the removal and photo-decolorization of azo carmosine dye (E122) as food dye using Rutile-TiO_2 suspension, *Egypt. J. Chem.*, 64 (9), 4857–4857.

[18] Al-Behadili, W.K.H., Jawad, Y.M., and Abdul Whaab, W.S., 2023, Effect of solvent on intensity of absorption and fluorescence of eosin Y dye and spectral properties of eosin Y dye, *J. Med. Chem. Sci.*, 6 (2), 322–334.

[19] Khan, M.M., and Abdulwahab, K.O., 2024, Metals- and non-metals-doped ZnS for various photocatalytic applications, *Mater. Sci. Semicond. Process.*, 181, 108634.

[20] Zhang, J., Qi, K., Pitcheri, R., and Duan, C., 2025, Engineering ZnS quantum dots for photocatalysis: Synthesis, modifications, and multifunctional applications, *J. Photochem. Photobiol., C*, 65, 100722.

[21] Liu, B., Li, X., Zhang, L., Ma, C., Chen, Y., Wang, X., Wei, H., and Wang, P., 2025, *In situ* crystalline growth ZnS nanoparticles on conjugated polymer for enhancement of the photocatalytic performance, *Polymers*, 17 (5), 575.

[22] Fakhri, F.H., and Ahmed, L.M., 2019, Incorporation CdS with ZnS as nanocomposite and using in photo-decolorization of Congo red dye, *Indones. J. Chem.*, 19 (4), 936–943.

[23] Kareem, E.T., Chafat, A.H., and Al-Da'amy, M.A., 2023, Iraqi porcelanite rocks for efficient removal of safranin dye from aqueous solution, *Baghdad Sci. J.*, 20 (2), 15.

[24] Taufik, A., Saleh, R., Sekino, T., and Yin, S., 2025, Mid-gap states induced by sulfur substitution in ZnO nanoparticle via low solvothermal temperature for enhanced photocatalytic NO_x removal under visible light irradiation, *Mater. Sci. Semicond. Process.*, 189, 109299.

[25] Ahmed, S., 2004, Photo electrochemical study of ferrioxalate actinometry at a glassy carbon electrode, *J. Photochem. Photobiol., A*, 161 (2), 151–154.

[26] Jawad, T.M., and Ahmed, L.M., 2020, Direct ultrasonic synthesis of WO_3/TiO_2 nanocomposites and applying them in the photodecolorization of eosin yellow dye, *Period. Tche Quim.*, 17 (34), 621–633.

[27] Taha, D.N., Mohammed, L.A., Farhood, A.S., and Ali, I.N.A., 2014, Adsorption of Janus green B dye from industrial waste water on the pistachio shells, *Eng. Technol. J.*, 32 (13), 3106–3119.

[28] Zwier, F.B., Al-Da'amy, M.A., and Kareem, E.T., 2024, Snail shell (*Rostellariella*) as a low-cost adsorbent for safranine dye removal from aqueous solution, *Baghdad Sci. J.*, 21 (4), 14.

[29] Athab, Z.H., Halbus, A.F., Mohammed, S.B., Atiyah, A.J., Ismael, H.I., Saddam, N.S., Baqir, S.J., Alesary, H.F., Algburi, S., and Al-Ansari, N., 2024, Comparison activity of pure and chromium-doped nickel oxide nanoparticles for the selective removal of dyes from water, *Sci. Rep.*, 14 (1), 4032.

[30] Abed, A.Q., Al Hindawi, A.M., and Alesary, H.F., 2023, Synthesis and characterization of zinc sulfide nanomaterials for removal methylene blue dye from aqueous solution, in *AIP Conf. Proc.,* 2830 (1), 020001.

[31] Mansoor, H.S., Salman, T.A., and Dhahir, S.A., 2025, Synthesis of titanium dioxide nanoparticles for removal of Pb^{2+}, Cd^{2+} and Cr^{3+} from wastewater, *Indones. J. Chem.*, 25 (5), 1350–1360.

[32] Abbas, S.K., Hassan, Z.M., Fakhri, F.H., Abdulhasan, H.F., and Ali, W.A., 2025, Design, fabrication, and characterization of n-doped decorated CeO_2 composite for degradation of malachite green, *J. Nanostruct.*, 15 (2), 631–638.

[33] Hameed, M.A., and Ahmed, L.M., 2024, Controllable cetrimide – assisted hydrothermal synthesis of $MoFe_2O_4$ and coupling with Al_2O_3 as an effective photocatalyst for decolorization of indigo carmine dye, *Indones. J. Chem.*, 24 (1), 170–184.

[34] Hoang, N.T.T., and Nguyen, D.D., 2023, Improving the degradation kinetics of industrial dyes with chitosan/TiO_2/glycerol films for the sustainable recovery of chitosan from waste streams, *Sustainability*, 15 (8), 6979.

[35] Ridha, N.J., Mohamad Alosfur, F.K., Kadhim, H.B.A., and Ahmed, L.M., 2021, Synthesis of Ag decorated TiO_2 nanoneedles for photocatalytic degradation of methylene blue dye, *Mater. Res. Express*, 8 (12), 125013.

[36] Seyed-Dorraji, M.S., Daneshvar, N., and Aber, S., 2009, Influence of inorganic oxidants and metal ions on photocatalytic activity of prepared zinc oxide nanocrystals, *Global NEST J.*, 11 (4), 535–545.

[37] Kant, P., Trinkies, L.L., Gensior, N., Fischer, D., Rubin, M., Alan Ozin, G., and Dittmeyer, R., 2023, Isophotonic reactor for the precise determination of quantum yields in gas, liquid, and multi-phase photoreactions, *Chem. Eng. J.*, 452, 139204.

[38] Taj-Aldeen, R.A., Alqaraguly, M.B., Salah, O.H., Abdulwahid, A.S., Hanoon, T.M., Abud Alzahraa, Z.H., and Omran, A.A., 2024, Enhanced photocatalytic performance of ZnO NPs in the presence of solar light and H_2O_2 for degradation of tetracycline from wastewater: Optimal conditions for green products, *Adv. J. Chem., Sect. A*, 7 (4), 396–405.

[39] Chatib, B., Laftani, Y., Boussaoud, A., and Hachkar, M., 2025, Ponceau S dye removal using UV/chlorine process: Affecting factors, cod removal and comparison with UV/H_2O_2 and UV/persulfate systems, *Indones. J. Chem.*, 25 (2), 371–380.

[40] Abdulamer, R., Fathallah, T.Z., Sattar, R., Naeem, Y.A., Idan, A.H., Kyhoiesh, H., and Nasr, Y.M., 2025, Enhanced photocatalytic removal of direct yellow 50 by ZnO/MWCNTs nanocomposite under solar light irradiation through response surface methodology (RSM) optimization co-doping orange G photodegradation sol-gel method Cu-Mg-TiO_2, *Adv. J. Chem., Sect. A*, 8 (1), 97–106.

[41] Gálvez, J.B., and Rodríguez, S.M., 2010, "Solar Photochemistry" in *Solar Energy Conversion and Photoenergy Systems: Thermal Systems and Desalination Plants-Volume II*, EOLss Publisher, Oxford, UK, 67–95.

[42] Bezerra, K.C.H., Fiaschitello, T.R., Labuto, G., Freeman, H.S., Fragoso, W.D., da Costa, S.M., and da Costa, S.A., 2021, Reuse of water from real reactive monochromic and trichromic wastewater for new cotton dyes after efficient treatment using H_2O_2 catalyzed by UV light, *J. Environ. Chem. Eng.*, 9 (4), 105731.

[43] Mansour, M.S., Farid, Y., Nosier, S.A., Adli, O., and Abdel-Aziz, M.H., 2023, Removal of Eosin Yellow dye from industrial wastewater using UV/H_2O_2 and photoelectro-Fenton techniques, *J. Photochem. Photobiol., A*, 436, 114411.

[44] Alamir, H.T.A., Reidh Abass, R., Salah, O.H., Karim, M.M., Ahjel, S., Al-Shuwaili, S.J., Kadhim, W.D., and Ahmed, R.A., 2024, Photocatalytic degradation of amoxicillin drug using ZnO/CdS nanocomposite for aqueous solutions by using AOPs, *Adv. J. Chem., Sect. A*, 7 (4), 438–447.

[45] Saeed, S.I., Taresh, B.H., Ahmed, L.M., Haboob, Z.F., Hassan, S.A., and Jassim, A.A.A.A., 2021, Insight into the oxidant agents effect of removal and photo-decolorization of Vitamin B12 solution in drug tablets using ZrO_2, *J. Chem. Health Risks*, 11 (4), 393–402.

[46] Shuvo, M.S.H., Putul, R.A., Hossain, K.S., Masum, S.M., and Molla, M.A.I., 2024, Photocatalytic removal of metronidazole antibiotics from water using novel Ag-N-SnO_2 nanohybrid material, *Toxics*, 12 (1), 36.

[47] Utami, N.P., Kurniawan, R., Pradipta, M.F., and Syoufian, A., 2025, Synthesis of zinc-nitrogen-codoped zirco-titania composite (Zn-N-codoped ZT) as a photocatalyst for photodegradation of phenol under visible light irradiation, *Indones. J. Chem.*, 25 (4), 1038–1050.

[48] Shen, L., Yan, B., Li, X., and Zhang, C., 2014, Electrochemiluminescence and electrochemistry from ZnO nanoparticles in alkaline aqueous solution with peroxydisulfate, *Nano*, 9 (4), 1450052.

[49] Fan, F., Povedailo, V.A., Lysenko, I.L., Seviarynchyk, T.P., Sharko, O.L., Mazunin, I.O., and Shmanai, V.V., 2024, Fluorescent properties of cyanine dyes as a matter of the environment, *J. Fluoresc.*, 34 (2), 925–933.

[50] Sun, L., and Bolton, J.R., 1996, Determination of the quantum yield for the photochemical generation of hydroxyl radicals in TiO_2 suspensions, *J. Phys. Chem.*, 100 (10), 4127–4134.

[51] Wang, Y., Wu, B., Zheng, X., Chen, B., and Chu, C., 2023, Assessing the quantum yield spectrum of photochemically produced reactive intermediates from black carbon of various sources and properties, *Water Res.*, 229, 119450.

[52] Silva, M., Trigueiro, P., Jerônimo, A., Barbosa, R., Lins, A., Albuquerque, W., Araujo, F.P., Osajima, J.A., and Peña-Garcia, R.R., 2024, Eco-friendly synthesis of $Zn_{0.97}La_{0.03}O$ compound with natural polysaccharide and its application in methylene blue and eosin dyes discoloration, *Mater. Lett.*, 363, 136256.

[53] Kustomo, K., and Wu, X., 2025, Photocatalytic deactivation of *E. coli* bacteria by copper(II) oxide doped-titanium dioxide nanocomposite in water catchment systems, *Indones. J. Chem.*, 25 (5), 1396–1409.

[54] Haruna, M., Bandoh, C.K., Agorku, E.S., Opoku, F., Asare-Donkor, N.K., and Adimado, A.A., 2024, Synthesis of La-doped ZrO_2/g-C_3N_4 nanocomposite for eosin yellow photodegradation: A combined experimental and theoretical studies, *Catal. Commun.*, 187, 106852.