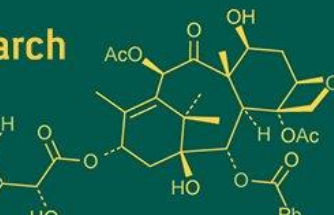
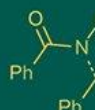


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Efficient degradation of acid blue 25 by UV-activated persulfate: Process optimization, kinetic modeling, mineralization, and degradation mechanism

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Abstract

The present study investigates the degradation of Acid Blue 25 (AB25) from aqueous solution using the ultraviolet/sodium persulfate (UV/ $\text{Na}_2\text{S}_2\text{O}_8$, UV/PS) advanced oxidation process. The effects of sodium persulfate dosage, initial solution pH, and initial dye concentration on the degradation efficiency were systematically evaluated under batch experimental conditions. In addition, the degradation kinetics were analyzed using the pseudo-first-order kinetic model, while the mineralization performance was assessed by measuring color, Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC) removal.

The experimental results demonstrated that the combined UV/PS process exhibited significantly higher degradation efficiency than UV irradiation or sodium persulfate alone, confirming the synergistic effect of persulfate activation under UV irradiation. The optimum degradation performance was achieved at a sodium persulfate dosage of 4.0 mM and an initial pH of 3. Increasing the initial dye concentration from 10 to 80 mg L^{-1} resulted in a gradual decrease in degradation efficiency due to increased pollutant loading and reduced availability of reactive sulfate radicals. The degradation kinetics followed the pseudo-first-order model with high coefficients of determination (R^2). Mineralization studies revealed that color removal was consistently higher than COD and TOC removal, indicating that decolorization occurred more rapidly than complete mineralization of the organic compounds.

Overall, the obtained results demonstrate that the UV/ $\text{Na}_2\text{S}_2\text{O}_8$ process is an effective and promising advanced oxidation technology for the treatment of Acid Blue 25-contaminated wastewater through efficient dye degradation and substantial mineralization under optimized operating conditions.

Keywords: Acid blue 25; advanced oxidation process, sodium persulfate, UV irradiation, sulfate radicals, dye degradation, mineralization, wastewater treatment

1. Introduction

The rapid growth of industrial activities has led to the continuous discharge of large quantities of dye-containing wastewater into aquatic environments (Lin *et al.*, 2023) [15]. Textile, leather, paper, cosmetic, pharmaceutical, and printing industries are among the major sources of colored effluents (Carmen & Daniela, 2012) [6]. These wastewaters contain complex organic compounds, which are not easily degraded and can remain in the environment for a long time. Manmade dyes are not only responsible for intense aesthetic pollution in water but also have the potential to decrease the penetration of light, to interfere with the photosynthetic activity, to diminish dissolved oxygen and to introduce negative impacts into the aquatic ecosystems. Besides this, some synthetic dyes and their degradation products are toxic, mutagenic and potentially carcinogenic causing serious harm to human beings and the environment (Satyam & Patra, 2024) [23].

Acid Blue 25 (AB25) is a dye of anionic azo type which is used in the textile industry and other industrial applications for its excellent color stability and high wash and light fastness properties (Muhd Julkapli *et al.*, 2014) [19]. These are also, however, desirable industrial properties and are a major challenge in wastewater removal. The presence of azo ($-\text{N}=\text{N}-$) chromophoric bond and aromatic ring structures makes Acid Blue 25 more chemically stable and resistant to the conventional biological treatment processes. Thus, the release of untreated dye containing waste water has emerged as an environmental issue and there is an urgent need for efficient and environmentally friendly treatment technologies (Gadipelly *et al.*, 2014) [8].

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Different techniques such as adsorption, coagulation-flocculation, membrane filtration, biological treatment, and chemical oxidation have been used to remove dye from wastewater (Bal & Thakur, 2022)^[5]. These techniques have shown different levels of effectiveness, but each has certain drawbacks. The adsorption and membrane processes primarily do not involve the complete destruction of pollutants and result in the transfer of pollutants from one phase to another, while coagulation generates a large volume of secondary sludge that needs to be disposed of (Sak *et al.*, 2026)^[22]. The biological treatment of azo dyes, in general, is not suitable due to their complex molecular structure and poor biodegradability, especially when the dyes are highly stable. Hence, the research and design of more efficient processing systems which can fully remove the persistent organic pollutants continues to be a significant priority (Bafana *et al.*, 2011)^[4].

Among the newer technologies, advanced oxidation processes (AOPs) are seen as one of the most promising solutions to tackle the refractory organic contaminants by producing highly reactive oxidizing species that can decompose the recalcitrant and complex organic molecules to simpler and less harmful molecules (Srivastav *et al.*, 2019)^[24]. Among them, the UV/ $\text{Na}_2\text{S}_2\text{O}_8$ (UV/PS) system has garnered significant interest as UV radiation can be used to effectively activate persulfate ions to generate sulfate radicals ($\text{SO}_4^{\bullet-}$) with a high oxidation potential and relatively long lifetime under appropriate conditions (Pal *et al.*, 2026)^[21]. The production of sulfate radicals and hydroxyl radicals in the simultaneous process has a synergistic effect on the degradation of persistent organic pollutants because the successive oxidation reactions happen which makes the UV/PS process an efficient wastewater treatment process for dye containing wastewater (Kuang *et al.*, 2023)^[13].

Although numerous studies have demonstrated the degradation behavior of a wide range of organic contaminants using Advanced Oxidation Processes (AOP) that employ persulfate, the degradation behavior, the kinetic characteristics, and the mineralization efficiency of Acid Blue 25 degradation through oxidation using UV/PS have thus far been limited. Moreover, the effects of the operating parameters (persulfate dosage, solution pH, initial dye concentration, etc.) should be thoroughly investigated to identify the optimal operating conditions for the treatment process and to better understand the degradation mechanism.

Thus, the aim of the present work is to study the degradation of Acid Blue 25 dye in aqueous solution by the UV/ $\text{Na}_2\text{S}_2\text{O}_8$ Advanced Oxidation Process. The effects of sodium persulfate dosage, initial solution pH, and initial dye concentration on the degradation efficiency were systematically evaluated. In addition, the degradation kinetics were analyzed using the pseudo-first-order kinetic model, while the mineralization performance was assessed through color, Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC) removal. Finally, a degradation mechanism was proposed to explain the oxidation pathway of Acid Blue 25 during the UV/PS process (Ghenaatgar *et al.*, 2019)^[9].

2. Materials and Methods

2.1 Chemicals and reagents

Acid Blue 25 (AB25) dye (90% purity, Sigma-Aldrich) was selected as the target organic contaminant in this study. Sodium persulfate ($\text{Na}_2\text{S}_2\text{O}_8$, 99% purity, Sigma-Aldrich) was employed as the oxidizing agent for the advanced

oxidation process. Hydrochloric acid (HCl, 1.0 N) and sodium hydroxide (NaOH, 1.0 N) were used to adjust the initial pH of the dye solutions. All solutions were prepared using distilled water without any further purification.

2.2 Preparation of dye stock solution

The stock solution of Acid Blue 25 dye (1000 mg L^{-1}) was prepared by dissolving 1.0 g of the dye in 1.0 L distilled water. The stock solution was kept in an amber (brown) glass bottle at room temperature and used at desired concentrations (10-80 mg L^{-1}) in distilled water.

2.3 UV-vis spectrophotometric analysis

The UV-Vis spectrometer (Shimadzu-UV-2450) was used for the determination of the maximum absorption wavelength (λ_{max}) of Acid Blue 25. The maximum absorbance of the dye was obtained at 603 nm, therefore, all the concentration measurements during the degradation experiments were made at 603 nm. A calibration curve was developed from a series of known dye solutions, which were prepared from the stock dye solution, and a linear relationship was found between absorbance and concentration that was used to find the concentration of the dye remaining during the experiments.

2.4 Experimental setup

The degradation experiments were performed in a 250 mL batch photoreactor. The reactor was fitted with a 36 W low-pressure mercury UV lamp that emits monochromatic radiation at 254 nm so as to irradiate the reaction solution uniformly. A magnetic stirrer with a stirring speed of 400 rpm was used to ensure good mixing of the reaction mixture during the entire experimental period. Each experiment was performed at the ambient temperature ($25 \pm 2^\circ\text{C}$). The desired pH of the dye solution (3, 5, 7, 9, or 11) was set at the start of the process by adding 1.0 N hydrochloric acid (HCl) or 1.0 N sodium hydroxide (NaOH). At specific time points (0, 5, 10, 20, 30, 40, 60, 80, and 100 min), 3 mL aliquots were removed and analyzed for each experiment. The concentration of Acid Blue 25 left over was measured spectrophotometrically at 603 nm. Each experiment was repeated three times and the results are given as an average of the three.

2.5 Experimental procedure

Batch degradation experiments were performed to assess the use of UV/ $\text{Na}_2\text{S}_2\text{O}_8$ process for removal of Acid Blue 25 from aqueous solution. The amount of the dye solution of desired initial concentration was 250 mL which was transferred to the photoreactor unless otherwise stated, and initial pH was adjusted using 1.0 N HCl or 1.0 N NaOH. Immediately prior to the UV irradiation, a known quantity of sodium persulfate was then added to the solution. A low-pressure mercury lamp with a 36 W UV radiation (254 nm) was used in the photoreactor. In all experiments, the distance between the UV lamp and the surface of the solution was kept constant at 5 cm to ensure the same conditions of irradiation. The reaction mixture was stirred constantly at 400 rpm throughout the reaction. Samples of 3 mL were collected at predetermined time intervals (0, 5, 10, 20, 30, 40, 60, 80, and 100 min). The amount of dye left was analyzed using a Shimadzu UV-Vis spectrophotometer measuring at the maximum absorption wavelength (603 nm). Each experiment was repeated three times and the mean values were used for data analysis.

2.6 Control experiments

Four experimental systems were tested under the same operating conditions: (i) dye solution without UV and sodium persulfate (Dye only), (ii) UV without sodium persulfate, (iii) sodium persulfate without UV (PS), and (iv) UV/ $\text{Na}_2\text{S}_2\text{O}_8$ combined process. The same concentration of initial dye, volume of dye solution, pH, temperature, and stirring speed were used for the experiments. A comparison of these systems was conducted to differentiate between the effects of direct photolysis, persulfate oxidation, and the combined effect from the synergistic action between UV activation of persulfate. Then the degradation efficiency achieved from each system was compared to determine the efficiency of sulfate radical-based advanced oxidation.

2.7 Determination of dye removal efficiency

The degradation efficiency of Acid Blue 25 was calculated from the reduction in the concentration of the dye during the oxidation process. UV-Vis spectrophotometric measurement of the unreacted (residual) dye concentration was done at 603 nm for various reaction times. The percentage removal of the dye was calculated using Equation (1):

$$\text{Removal (\%)} = (\text{Co} - \text{Ct}) / (\text{Co}) \times 100$$

Where (Co) (mg L^{-1}) is the initial dye concentration and (Ct) (mg L^{-1}) is the dye concentration at reaction time (t).

2.8 Kinetic analysis

The degradation kinetics of Acid Blue 25 dye in the process of UV/ $\text{Na}_2\text{S}_2\text{O}_8$ oxidation was tested and analyzed by the pseudo-first-order kinetic model. The kinetic equation is written like this:

$$\ln \text{Co}/\text{Ct} = kt$$

Where (k) (min^{-1}) is the apparent pseudo-first-order rate constant, (t) (min) is the reaction time, while (C_0) and (C_t) (mg L^{-1}) represent the initial and residual dye concentrations, respectively.

The apparent rate constant was obtained from the slope of the linear plot of ($\ln(\text{C}_0/\text{C}_t)$) versus reaction time, while the linearity of the kinetic model was evaluated using the coefficient of determination (R^2).

2.9 Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) analysis

Under the optimum operating conditions, the Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) of the treated solutions were measured to evaluate the mineralization efficiency of the UV/ $\text{Na}_2\text{S}_2\text{O}_8$ process. Samples were taken before and after the oxidation to assess the reduction of organic pollutants during the oxidation process.

The COD removal efficiency was calculated according to Equation (3):

$$\text{COD Removal (\%)} = (\text{COD}_0 - \text{COD}_t) / \text{COD}_0 \times 100$$

Where (COD_0) and (COD_t) represent the initial and final chemical oxygen demand (mg L^{-1}), respectively.

Similarly, the TOC removal efficiency was determined using Equation (4):

$$\text{TOC Removal (\%)} = (\text{TOC}_0 - \text{TOC}_t) / \text{TOC}_0 \times 100$$

Where (TOC_0) and (TOC_t) denote the initial and final total organic carbon concentrations (mg L^{-1}), respectively. The obtained COD and TOC removal efficiencies were used to evaluate the extent of mineralization achieved during the oxidation process.

3. Results and discussion

3.1 Calibration curve of acid blue 25

The maximum absorption wavelength (λ_{max}) of Acid Blue 25 was found to be 603 nm. Hence, the absorbance for all the degradation experiments was measured at this wavelength. Figure 1 shows the calibration graph of Acid Blue 25 derived from Acid Blue 25 standard solutions of different concentrations ($5\text{--}80 \text{ mg L}^{-1}$). A good linear correlation was obtained between absorbance and the concentration range of the dye studied. The results of the calibration equation and coefficient of determination (R^2) showed that the analytical method was excellent in terms of linearity. This calibration curve was then used to calculate the amount of dye remaining in all degradation experiments.

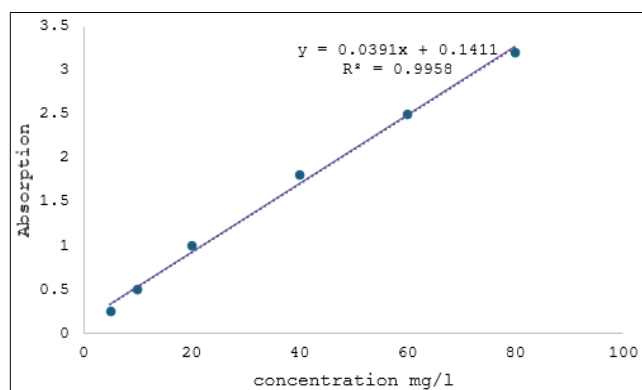
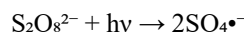


Fig 1: Calibration curve of Acid Blue 25 at $\lambda_{\text{max}} = 603 \text{ nm}$

3.2 Comparison of different oxidation systems

The degradation performance of Acid Blue 25 was examined in three different oxidation systems: UV alone, PS alone and UV/PS combined system under the same experimental conditions. The results obtained are shown in Figure 2. Comparing with UV irradiation and persulfate alone, it is observed that the combined UV/PS process was able to get a much higher degradation efficiency as shown in Figure 2. In the UV-only system, the dye molecules were only slightly degraded by direct photolysis in the UV radiation, while the oxidation efficiency in the PS-only system was relatively low because PS is a kinetically stable compound and does not have enough opportunity to generate reactive radicals without activation. However, the degradation ability was significantly improved when the two methods were combined, that is, when UV irradiation was combined with sodium persulfate. Such an improvement is believed to be caused by the photochemical activation of persulfate that generates the highly reactive sulfate radical ($\text{SO}_4^{\bullet-}$) via the following reaction: (Xia *et al.*, 2020) [27]



The generated sulfate radicals possess a high oxidation potential (2.5–3.1 V), enabling rapid cleavage of azo bonds and oxidation of aromatic structures in the Acid Blue 25 molecules. In addition, sulfate radicals may react with water to produce hydroxyl radicals ($\bullet\text{OH}$), providing an additional

oxidation pathway and further enhancing the degradation efficiency (Wang *et al.*, 2023) [26].

The comparison clearly demonstrates the synergistic effect between UV irradiation and persulfate activation. Therefore, the combined UV/PS process was selected for all subsequent experiments investigating the effects of sodium persulfate dosage, initial pH, initial dye concentration, reaction time, kinetic behavior, and mineralization efficiency.

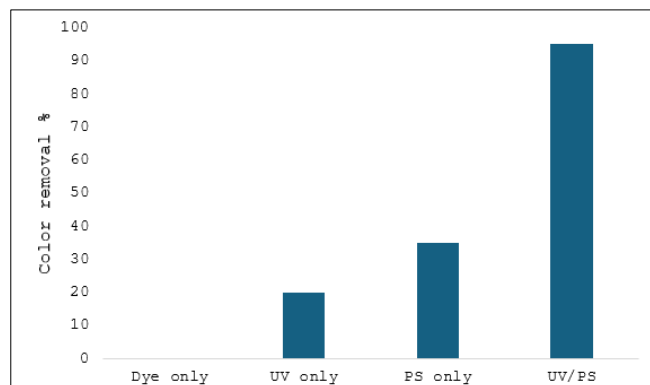


Fig 2: Comparison of Acid Blue 25 color removal efficiencies using different oxidation systems under identical experimental conditions

3.3 Effect of sodium persulfate dosage

The effect of sodium persulfate ($\text{Na}_2\text{S}_2\text{O}_8$) dosage on the degradation of Acid Blue 25 was investigated by varying the oxidant concentration from 0.5 to 4.0 mM while maintaining all other experimental conditions constant. The obtained results are presented in Figure 3.

The degradation efficiency of the combined UV/PS process markedly increased with increasing sodium persulfate dosage as shown in Figure 3. The color removal efficiency increased from 55 to 95% as the oxidant concentration increased from 0.5 mM to 4.0 mM, which shows that the oxidation performance strongly depended on the oxidant concentration.

The degradation efficiency of the UV-only and PS-only systems, on the other hand, was significantly lower across the whole range of dosage studied, with degradation efficiencies of 20% and 35% at the highest PS dosage, respectively. The significant improvement noted in the UV/PS system is due to the photochemical activation of persulfate with UV light to produce very reactive sulfate radicals ($\text{SO}_4^{\bullet-}$) that play a key role in the oxidation process. Such radicals have a high oxidation potential which attacks the azo bonds and/or aromatic structures of Acid Blue 25 and cause rapid degradation of the dye molecules. Moreover, the sulfate radicals can react with water to produce hydroxyl radicals ($\bullet\text{OH}$), which are an extra oxidation route and further enhances the degradation efficiency (Oni & Doğan, 2025) [20].

The poor performance of the UV-only system suggests that direct photolysis alone was not enough for efficient

degradation of Acid Blue 25. Likewise, persulfate alone exhibited limited oxidation efficiency because persulfate remains relatively stable in aqueous solution without activation. Therefore, the significantly higher degradation achieved by the combined UV/PS process confirms the strong synergistic effect between ultraviolet irradiation and sodium persulfate activation (Ahmed & Ealias, 2026) [2]. Within the investigated dosage range (0.5-4.0 mM), no decline in degradation efficiency was observed with increasing persulfate dosage. Therefore, 4.0 mM was selected as the optimum sodium persulfate concentration and was used in all subsequent experiments.

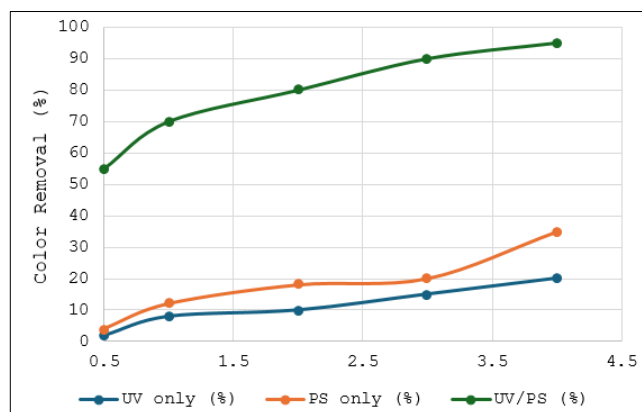


Fig 3: Effect of sodium persulfate dosage on the degradation of Acid Blue 25 using UV irradiation alone, persulfate alone (PS), and the combined UV/PS process

3.4 Effect of initial pH

The influence of the initial solution pH on the degradation of Acid Blue 25 was investigated over the pH range of 3-10 while maintaining all other operating parameters constant. The obtained results are presented in Figure 4.

As shown in Figure 4, the degradation efficiency of the UV/PS process was strongly affected by the initial solution pH. The maximum color removal efficiency (95%) was obtained at pH 3. The degradation efficiency decreased gradually with increasing pH to 85%, 75%, 60% and 40% at pH 5, 7, 9 and 10 respectively. The degradation efficiencies of the other two systems (UV-only and PS-only) were however significantly lower in comparison across the entire pH range.

The enhanced degradation under acidic conditions is mainly attributed to the efficient activation of persulfate by UV irradiation, leading to the formation of highly reactive sulfate radicals ($\text{SO}_4^{\bullet-}$). These radicals have a high oxidation potential and can easily oxidize the azo bonds and aromatic structures of Acid Blue 25. Under alkaline conditions, sulfate radicals are progressively converted into hydroxyl radicals ($\bullet\text{OH}$), while competing side reactions and radical scavenging reduce the concentration of reactive oxidizing species available for dye degradation (Kumari & Pulimi, 2023) [14].

The results clearly demonstrate that acidic conditions significantly enhance the performance of the UV/PS process. Therefore, pH 3 was selected as the optimum initial pH for all subsequent experiments (Arman *et al.*, 2024) [3].

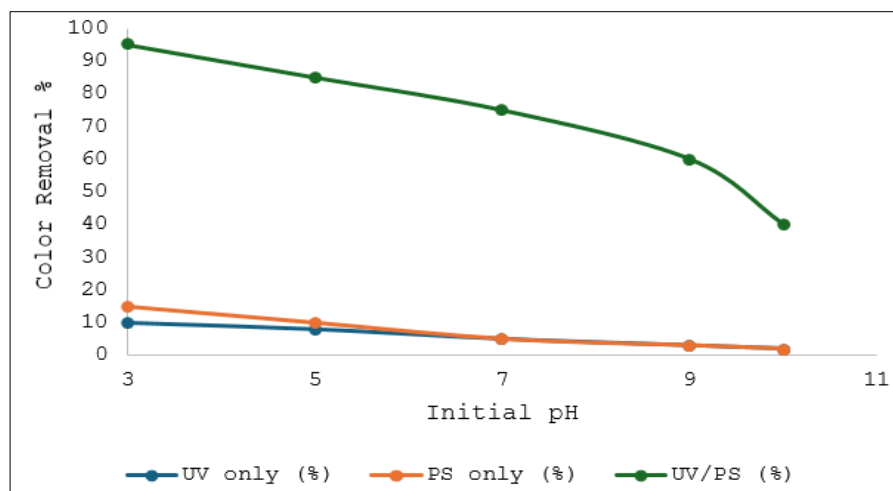


Fig 4. Effect of initial pH on the degradation of Acid Blue 25 using UV irradiation alone, persulfate alone (PS), and the combined UV/PS process

3.5 Effect of initial dye concentration

The influence of the initial Acid Blue 25 concentration on the degradation efficiency of the UV/PS process was investigated using dye concentrations of 10, 20, 40, 60, and 80 mg L⁻¹ while maintaining the optimum operating conditions established in the previous experiments. The obtained results are presented in Figure 5. As shown in Figure 5, the degradation efficiency increased with reaction time for all investigated dye concentrations. However, the overall removal efficiency decreased as the initial dye concentration increased. After 100 min of treatment, the color removal efficiencies reached 99%, 97%, 91%, 83%, and 73% for initial dye concentrations of 10, 20, 40, 60, and 80 mg L⁻¹, respectively. The higher degradation efficiency observed at lower dye concentrations is attributed to the greater availability of reactive sulfate radicals (SO₄•⁻) relative to the number of dye molecules present in the solution. In these conditions, there were enough reactive

radicals to adequately attack the azo bonds and aromatic structures of Acid Blue 25, and its rapid degradation was observed. With an increase in the initial dye concentration, there were more dye molecules available to compete for the available reactive radicals. Furthermore, there was greater UV light absorption by the concentrated dye solutions, which resulted in less light penetration in the solution, and lower activation efficiency of sodium persulfate. Moreover, the degradation intermediates which are formed during the oxidation process can also compete with the parent dye molecules to collect the available reactive species, thus decreasing the degradation efficiency (Thakur *et al.*, 2010)^[25]. The results show that the initial dye concentration has a notable effect on the effectiveness of the UV/PS oxidation process. Under the experimental conditions explored, lower initial concentrations lead to faster degradation and higher color removal efficiencies (Mechehoud *et al.*, 2026)^[17].

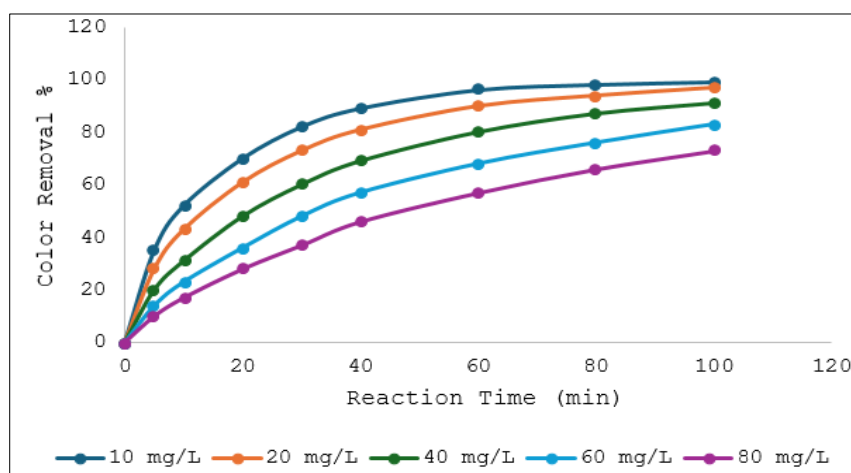


Fig 5: Effect of the initial Acid Blue 25 concentration on the degradation efficiency of the UV/PS process under the optimum operating conditions

3.6 Kinetic study

The pseudo-first-order kinetic model was used to investigate the degradation kinetics of Acid Blue 25 in the UV/PS oxidation process. The plots showing the relationship between $\ln(C_0/C_t)$ and reaction time for various initial dye concentrations are shown in Figure 6 and the related kinetic parameters are listed in Table 1.

All the kinetic plots obtained were found to be linear with a good correlation coefficient ($R^2 = 0.9655-0.9940$), suggesting the degradation of Acid Blue 25 could be well represented by pseudo-first-order kinetic model. The apparent rate constants (k) were obtained from the slopes of the linear regression equations, which were found to be

0.0327 min⁻¹, 0.0185 min⁻¹ and 0.0124 min⁻¹ for the initial dye concentration of 10, 40 and 80 mg L⁻¹ respectively.

The results have indicated that the apparent degradation rate decreased with an increase in the initial dye concentration. This is due to the higher competition between the available dye molecules for the available sulfate radicals and to the lower penetration of the UV light at higher dye concentration. Hence, the ability to generate reactive species decreased and the degradation rate decreased as well.

The excellent agreement between the experimental data and the pseudo-first-order kinetic model confirms that the UV/PS process efficiently degrades Acid Blue 25 under the investigated operating conditions. Furthermore, the kinetic results are consistent with the degradation efficiencies presented in the previous section, where lower initial dye concentrations exhibited faster degradation and higher removal efficiencies (Muhammad *et al.*, 2025)^[18].

Table 1: Pseudo-first-order kinetic parameters for the degradation of Acid Blue 25 using the UV/PS process

Initial concentration (mg/L)	k (min ⁻¹)	R ²
10	0.0327	0.9917
40	0.0185	0.994
80	0.0124	0.9655

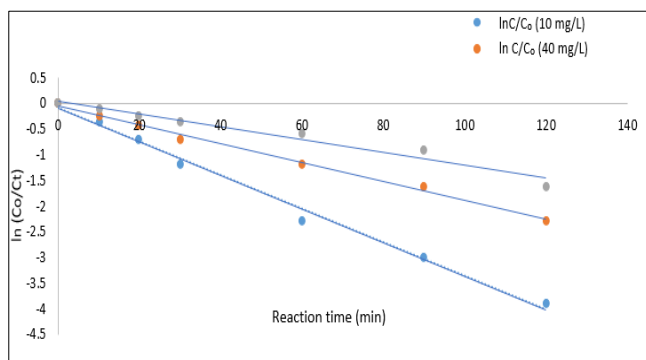


Fig 6: Pseudo-first-order kinetic plots for acid blue 25 degradation at different initial dye concentrations

3.7 Mineralization efficiency

Following the evaluation of the degradation kinetics, the mineralization performance of the UV/PS process was further assessed under the optimum operating conditions by measuring color, chemical oxygen demand (COD), and total organic carbon (TOC) removal at different initial Acid Blue 25 concentrations. The obtained results are presented in Figure 7 and summarized in Table 2.

Figure 7 shows that the efficiencies of dye removal, COD removal and TOC removal decreased gradually as the initial dye concentration was increased. The UV/PS process was able to remove 99% of the color, 82% of COD and 72% of TOC in an initial concentration of 10 mg L⁻¹. For the initial dye concentration of 80 mg L⁻¹, removal efficiencies were 73%, 45% and 34% for the three parameters, respectively. It shows that the pollutant loading had a negative impact on the dye degradation and the efficiency of mineralization as more pollutants were added. The parameters studied showed that the color removal was consistently higher in the entire range of concentration as compared to COD and TOC removal. The discovery of this suggests that the chromophoric azo groups that give the color were quickly broken down on oxidation and the mineralization of the resulting degradation intermediates needed further oxidation processes. Thus, the decolorization was well performed

without the complete conversion of the organic carbon into carbon dioxide and water (GilPavas & Correa-Sanchez, 2020)^[10]. The progressive decrease in COD and TOC removal with the increased dye concentration may be due to the reduction of sulfate radicals' (SO₄•⁻) availability and the increase in dye molecules. As initial concentration increased there was more competition for the reactive radicals and this led to less effectiveness of the radicals in oxidizing the parent dye as well as the intermediate products of the dye. Furthermore, loss of some of the produced oxidizing species by reaction with degradation intermediates and the decrease in UV light transmittance in the dye solution due to the high dye concentration also resulted in a lower activation of persulfate and sulfate radical production (Ahlawat *et al.*, 2024)^[11]. The mineralization was not achieved within the reaction time investigated, but the relatively high COD and TOC removal efficiency for lower dye concentrations suggests that the UV/PS process is able to oxidize a significant fraction of the organic matter besides the dye color. The results show that the UV/PS process can effectively decolorize and mineralize the Acid Blue 25 dye, especially at low initial concentrations of the dye, indicating its potential as an effective advanced oxidation process for Acid Blue 25 contaminated wastewater treatment (Iqbal *et al.*, 2024)^[11].

Table 2: Mineralization efficiency of the UV/PS process at different initial Acid Blue 25 concentrations

Initial AB25 (mg/L)	Color removal (%)	TOC removal (%)	COD removal (%)
10	99	72.03	82
20	97	65.00	76
40	91	53.98	66
60	83	42.99	55
80	73	34.00	45

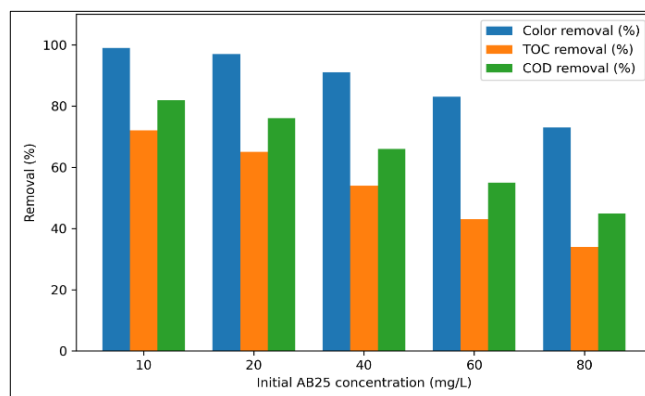
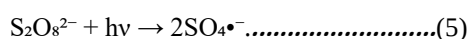


Fig 7: Effect of the initial Acid Blue 25 concentration on color, chemical oxygen demand (COD), and total organic carbon (TOC) removal efficiencies by the UV/Na₂S₂O₈ process under the optimum operating conditions

3.8 Proposed degradation mechanism

The degradation of Acid Blue 25 by the UV/Na₂S₂O₈ process is primarily initiated through the photolytic activation of persulfate under UV irradiation. Upon exposure to ultraviolet light (254 nm), the persulfate ion undergoes homolytic cleavage, producing two highly reactive sulfate radicals (SO₄•⁻), as described by Equation (5): (Jajarmi *et al.*, 2025)^[12]



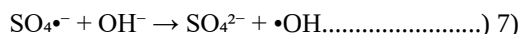
The generated sulfate radicals are strong oxidizing species with a standard oxidation potential of approximately 2.5-3.1

V. These radicals readily attack the chromophoric azo bond ($-N=N-$) and the aromatic rings of Acid Blue 25, leading to cleavage of the dye structure and rapid decolorization.

In aqueous solution, sulfate radicals may further react with water molecules or hydroxide ions to produce hydroxyl radicals ($\bullet OH$), providing an additional oxidation pathway:



and



All the above redox reactions bring about successive oxidation of the parent dye molecules which ultimately leads to the rupture of azo linkages, opening of aromatic rings and formation of low molecular weight organic intermediates like organic acids. Further oxidation eventually leads to complete or partial conversion of these intermediates to carbon dioxide, water and inorganic ions.

In this study, the experimental results are in good agreement with the proposed degradation mechanism. This is seen from the considerably higher color removal efficiency than the COD and TOC removal, showing that the destruction of the chromophoric groups was faster than the complete mineralization of organic carbon. Additionally, the observed drop in degradation efficiency with increasing initial dye concentrations may be due to competition from degradation intermediates for the reactive radicals and to the fact that the UV light penetration is reduced and the persulfate activation efficiency is decreased at high initial dye concentrations (Liu *et al.*, 2014)^[16].

Hence, the degradation of Acid Blue 25 in the UV/PS process is mainly controlled by the action of sulfate radicals ($SO_4^{\bullet-}$) and hydroxyl radicals ($\bullet OH$), which would lead to effective decolorization and a slow mineralization process of the formed oxidation intermediates (Ding *et al.*, 2020)^[7].

4. Conclusion

In this study, the UV/ $Na_2S_2O_8$ (UV/PS) advanced oxidation process (AOP) was successfully used for the degradation of Acid Blue 25 (AB25) from aqueous solution. Experimental results showed that the degradation efficiency of the combined UV/PS system was much more efficient than that of UV irradiation alone and persulfate alone, which can be attributed to the synergy of persulfate activation under UV irradiation.

The operating parameters had a significant influence on the degradation efficiency. A sodium persulfate concentration of 4.0 mM and a pH of the initial solution of 3 yielded the best color removal. As the concentration of the dye increased from 10 to 80 mg L⁻¹, the degradation efficiency decreased gradually because of the increased pollutant loading and reduced availability of reactive sulfate radicals. The pseudo-first-order kinetic model was successfully applied to describe the degradation kinetics of Acid Blue 25 with a high coefficient of determination (R^2) which indicated good agreement between the experimental data and kinetic model.

Mineralization studies demonstrated that the color removal efficiency was always higher than COD and TOC removal efficiency, thus decolorization was faster than the complete mineralization of the organic compounds. However, COD and TOC reductions were significant with the UV/PS

process indicating that a considerable portion of the organic matter could be oxidized.

In general, the results obtained show that the UV/PS process is an efficient and promising advanced oxidation technology for treating the Acid Blue 25 contaminated wastewater especially at low initial concentrations of the dye and at acidic pH.

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