Indian Journal of Chemical Technology
Vol. 32, September 2025, pp. 644-649
DOI: 10.56042/ijct.v32i5.14132

Photocatalytic degradation of Bisphenol A using hybrid oxalate-pyrite/chitosan

R.R. Sugumaran[1], H. Abdullah[1, *], J. H. Shariffuddin[1], F. Aziz[2], N.S. Sambudi[3] & A.N. Rosli[4]

[1]Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Gambang, Pahang, Malaysia

[2]School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, Malaysia

[3]Department of Chemical Engineering, Universitas Pertamina, Simprung, Jakarta Selatan, 12220, Indonesia

[4]Faculty of Science and Technology, Universiti Sains Islam Malaysia, Bandar Baru Nilai, 71800, Nilai, Negeri Sembilan, Malaysia

*E-mail: hamidah@umpsa.edu.my

Received 3 October 2024; accepted 16 September 2025

This study investigated the photocatalytic degradation of Bisphenol A (BPA) using a low-cost and environmentally friendly hybrid catalyst composed of oxalate-pyrite/chitosan. The effects of initial BPA concentration, catalyst dosage, and pH on the percentage of BPA degradation are examined. Additionally, both adsorption and photocatalytic degradation kinetics are evaluated. The findings revealed that BPA degradation is most effective at a lower initial concentration (5 mg/L) and at neutral pH (pH 7). Moreover, increasing the catalyst dosage led to a rise in photodegradation efficiency, although the improvement is not significant. The adsorption of BPA onto the hybrid oxalate-pyrite/chitosan catalyst conformed to the pseudo-second-order kinetic model, while the photocatalytic degradation followed pseudo-first-order reaction kinetics.

Keywords: Bisphenol A (BPA), Kinetics, Oxalate-pyrite/chitosan, Photocatalytic degradation

Introduction

Bisphenol A (BPA) is a widely used chemical in the plastic manufacturing industry and can be discharged into wastewater. This compound is known to be toxic to aquatic organisms, negatively impacting their growth, reproduction, development, and survival. In addition, BPA contamination can also lead to pollution of soil and groundwater. According to a study by Haron *et al*., tap water samples collected from the Klang Valley, Malaysia, contained BPA levels that exceeded the acceptable daily limits established by international standards[1]. Therefore, managing BPA in wastewater generated by plastic industries is vital to reduce its environmental impact. Implementing effective treatment methods is essential to minimize the presence of such chemicals in wastewater, thereby safeguarding aquatic ecosystems and human health.

Among various treatment methods, heterogeneous photocatalysis and adsorption have been recognized as effective techniques for removing pollutants from the liquid phase[2-4]. However, conventional wastewater treatment approaches that rely solely on either adsorption or photocatalysis often face limitations such as poor stability, low selectivity, and slow reaction rates. These shortcomings hinder the complete removal of certain pollutants from wastewater[5], thereby encouraging the development and investigation of hybrid treatment techniques.

A hybrid approach that integrates photocatalysts and adsorbents has shown promise in overcoming the limitations of individual treatment methods. Oyim *et al*. reported enhanced performance using a hybrid system based on porphyrin anchored onto activated carbon granules[6]. The combination of photocatalytic and adsorptive components in a single system introduces synergistic effects, allowing each material to offset the weaknesses of the other. Additionally, the hybrid structure offers a larger surface area for interactions between the photocatalyst and target pollutants, leading to improved degradation efficiency. Although various chemicals have been employed to synthesize hybrid photocatalyst/adsorbent materials with promising results, many of these substances are synthetic and costly, posing challenges for large-scale applications.

In this study, a hybrid photocatalyst/adsorbent system combining oxalate-pyrite as the photocatalyst and chitosan as the adsorbent was investigated. Pyrite (FeS_2), a sulfide mineral, is a naturally abundant material that has been widely used in the photocatalytic degradation of wastewater contaminants such as malachite green (MG), Cr(VI)[8], methylene blue and phenol[9] and others. Chitosan, a biopolymer derived from renewable and biodegradable sources, is well-known for its high adsorption capacity, making it a popular choice among researchers for the adsorption of organic pollutants[10,11]. Thus, the combination of these two materials presents a sustainable, environmentally friendly, and cost-effective solution for pollutant removal.

The aim of this study is to evaluate the degradation potential of Bisphenol A (BPA) using a hybrid oxalate-pyrite/chitosan catalyst by examining the effects of initial BPA concentration, catalyst dosage, and pH. In addition, a kinetic study was also conducted.

Experimental Section

Materials

The chemicals used in this experimental study include 97% purity Bisphenol A (BPA) from Sigma-Aldrich, which served as the model compound. Sodium hydroxide and hydrochloric acid were employed to adjust the pH levels. The oxalate-pyrite/chitosan catalyst was synthesized following the procedure outlined in our previous study[12].

Photocatalytic Study

The photocatalytic experiments were conducted in a quartz reactor, where the BPA solution and the synthesized catalyst were placed together. The reactor was then exposed to visible light at room temperature. The effects of initial BPA concentration (ranging from 5 to 20 ppm), catalyst dosage (0.5 to 6.0 g/L), and initial pH of the BPA solution (from pH 3 to 11) were investigated. Samples were collected at 10 min intervals, and the BPA concentration in each sample was determined based on absorbance measurements using a GENESYS UV-Vis spectrophotometer. The degradation efficiency was calculated using Eq. (1).

$$\%\, degradation = \frac{C_o - C_t}{C_o} x\, 100 \quad \text{... (1)}$$

Where, C_o is the initial BPA concentration and C_t is the final BPA concentration.

Kinetic study

The kinetic study was carried out by conducting two sets of experiments: one involving BPA adsorption in the absence of light irradiation, and the other involving BPA photocatalytic degradation under the optimum conditions identified in the photocatalytic study section. Samples were extracted at 10 min intervals, and their concentrations were measured until equilibrium was reached. The amount of BPA adsorbed was calculated using Eq. (2).

$$QuantityofBPAadsorbed(q_e) = \frac{C_o - C_t}{C_o} x \frac{V}{W}. \quad \text{... (2)}$$

Where, V is the volume of BPA solution and W is the mass of catalyst.

Two kinetic models were applied to study the adsorption behaviour of BPA: the pseudo-first order and pseudo-second-order models, represented by Eqs (3) and (4), respectively. For photocatalytic degradation kinetics, the Langmuir-Hinshelwood model was employed. This model was subsequently simplified to an apparent first-order rate expression, as shown in Eq. (5)[13].

$$\log(q_e - q_t) = \log q_e - \left(\frac{k_1}{2.303}\right) t \quad \text{... (3)}$$

$$\frac{1}{q_t} = \frac{1}{k_2 {q_e}^2} + \left(\frac{1}{q_e}\right) t \quad \text{... (4)}$$

$$ln \frac{Initial\ BPA\ concentration}{BPA\ concentration\ at\ time\ t} = k_1 t \quad \text{... (5)}$$

Results and Discussion

Photocatalytic degradation of BPA and PA using chitosan, oxalate-pyrite and hybrid oxalate-pyrite/chitosan

Fig. 1 clearly demonstrates that the highest BPA degradation is achieved when using the hybrid oxalate-pyrite/chitosan catalyst, compared to using oxalate-pyrite or chitosan alone as the photocatalyst and adsorbent, respectively. Interestingly, chitosan alone resulted in 17.61% BPA degradation. However, this is likely not due to a photocatalytic reaction, but

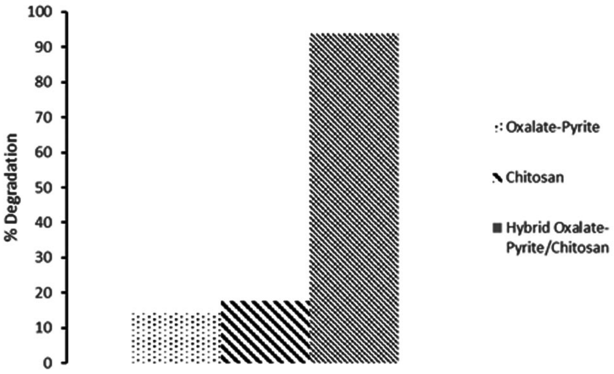

Fig. 1 — Photocatalytic degradation of BPA using chitosan and oxalate-pyrite individually, compared to the hybrid oxalate-pyrite/chitosan catalyst. Experimental conditions: reaction time = 40 min, pH = 7, initial BPA concentration = 5 ppm, and catalyst dosage = 0.5 g/L

rather attributed to the adsorption process, as chitosan is known to be an effective adsorbent[10]. It strongly adsorbs BPA from solution due to its amino and hydroxyl functional groups[14].

Besides, the performance of oxalate-pyrite in the BPA photodegradation was expected due to the pyrite (FeS_2) serving as the semiconductor photocatalyst. FeS_2 has a narrow band gap enabling visible absorption. Thus, it can generate electron-hole pairs when irradiated under visible light irradiation. These photoexcited charge carriers drive redox reactions: photogenerated holes oxidize water or hydroxide to produce •OH radicals, while electrons reduce O_2 to O_2•−. In essence, pyrite is an active ROS generator under light, analogous to how TiO_2 functions under UV. Pyrite's contribution has been confirmed by prior studies demonstrating efficacy of FeS_2 in degrading pollutants like dyes and phenols[9,15]. Moreover, addition of oxalate greatly boosts •OH generation beyond what pyrite alone would achieve. Oxalate acts as a photo-Fenton co-catalyst and ligand that enhances ROS generation. Under light, Fe(III)-oxalate complexes undergo photolysis via ligand-to-metal charge transfer, yielding Fe(II) and organic radicals (e.g. CO_2•−). These radicals rapidly react with O_2 to produce superoxide and hydrogen peroxide (H_2O_2). The H_2O_2 can then be converted (via Fenton or photo-Fenton reactions with Fe(II)/Fe(III)) into additional •OH radicals. In this way, the oxalate augments the ROS pool by continually cycling iron between Fe(III) and Fe(II) under illumination[16].

Thus, the integration of chitosan and oxalate-pyrite catalyst boost the performance to 93.89% BPA degradation. Adsorption efficiently removes BPA, while photocatalysis, activated by light exposure, generates reactive hydroxyl radicals(OH) radicals. These •OH radicals attack BPA's aromatic structure and cleave it into less harmful products[17]. This assignment is consistent with the general mechanism of semiconductor photocatalysis, where photoexcited electron-hole pairs yield these ROS that in turn mineralize organic pollutants[18]. In addition to removing pollutants, the adsorbent component also enhances the interaction between contaminants and the photocatalyst by concentrating the pollutants on its surface. This increased contact promotes the photocatalytic degradation of pollutants adsorbed onto the adsorbent, thereby improving overall treatment efficiency. By combining the advantages of both components, the hybrid system addresses the limitations associated with using oxalate-pyrite or chitosan individually, leading to a higher degradation rate and enhanced effectiveness in BPA removal.

The catalytic performance of the $NiAg_2O$/Lup@CS nanocomposite, which achieved 86.14 % and 85.65% degradation of crystal violet and malachite green oxalate, respectively[19], supports the present findings where the integration of chitosan with oxalate-pyrite catalyst further enhanced the degradation efficiency to 93.89% for BPA, emphasizing the synergistic advantage of combining biopolymer-based adsorbents with photocatalysts for effective pollutant removal.

Effect of initial concentration

Fig. 2 illustrates that the photocatalytic degradation of BPA gradually decreases as the initial BPA concentration increases from 5 to 20 ppm. This trend may be attributed to the increased number of BPA molecules adsorbed onto the surface of the photocatalyst at higher concentrations. As the concentration rises, the available active sites on the catalyst surface become saturated, limiting further degradation activity. Once these sites are fully occupied, fewer reactive sites remain available, leading to a reduction in overall photocatalytic efficiency[20]. As BPA molecules occupy a large portion of the active sites on the photocatalyst surface, the adsorption of oxygen and hydroxyl ions is reduced, thereby hindering the generation of reactive radicals essential for the degradation process[21].

Effect of catalyst dosage

Fig. 3 shows that the photocatalytic degradation of BPA increases with the catalyst dosage; however, the increase is not substantial. When exposed to light, the catalyst absorbs photons, generating electron-hole

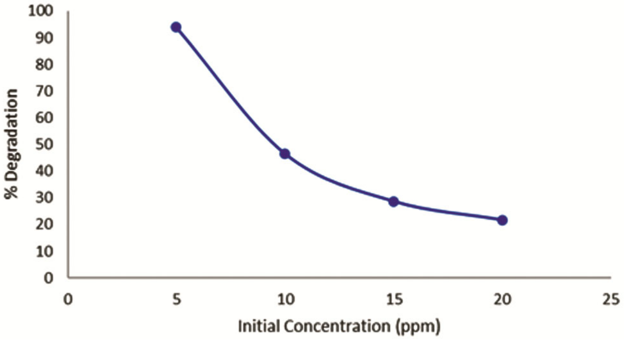

Fig. 2 — Effect of initial BPA concentration on the photocatalytic degradation efficiency using the hybrid oxalate-pyrite/chitosan catalyst. Experimental conditions: reaction time = 40 min, pH = 7, and catalyst dosage = 0.5 g/L

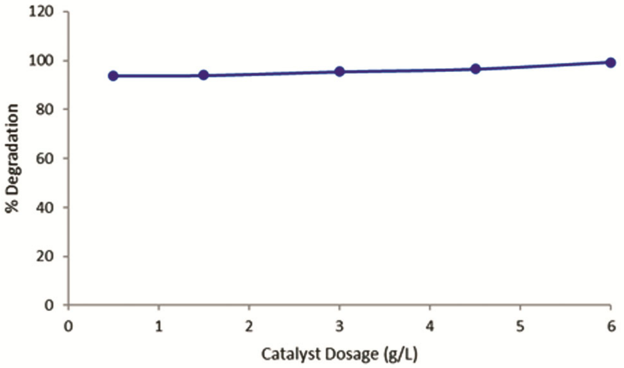

Fig. 3 — Effect of catalyst dosage on the photocatalytic degradation of BPA using the hybrid oxalate-pyrite/chitosan catalyst. Experimental conditions: reaction time = 40 min, pH = 7, and initial BPA concentration = 5 ppm

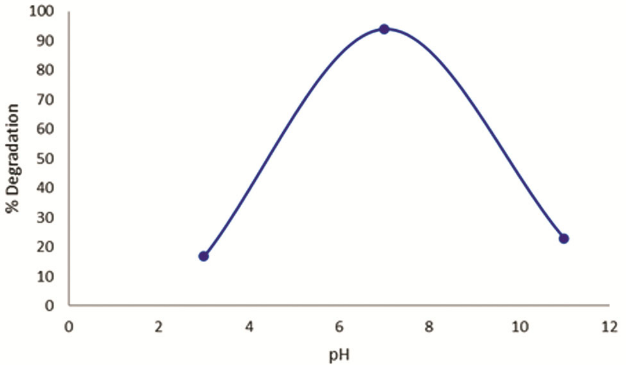

Fig. 4 — Effect of pH on the photocatalytic degradation of BPA using the hybrid oxalate-pyrite/chitosan catalyst. Experimental conditions: reaction time = 40 min, catalyst dosage= 0.5 g/L, and initial BPA concentration = 5 ppm

pairs. Increasing the amount of photocatalyst enhances the number of available active sites for photon absorption, thereby leading to the formation of more electron-hole pairs[22]. These electron-hole pairs are crucial for redox reactions on the catalyst surface, which in turn produce highly reactive hydroxyl radicals[23]. A higher generation rate of hydroxyl radicals enhances the photocatalytic degradation efficiency. As strong oxidizing agents, hydroxyl radicals attack organic pollutants, breaking down their molecular structures into less toxic or harmless by-products[17].

Effect of pH

Fig. 4 illustrates the effect of varying pH on the percentage of BPA photodegradation. The results indicate that optimal degradation occurs at pH 7. This could be attributed to the fact that both highly acidic and highly alkaline environments can inhibit the formation of hydroxyl radicals, which are crucial reactive species in photocatalysis responsible for breaking down pollutants. At extreme pH levels, the generation and reactivity of these radicals are suppressed, leading to slower degradation rates. This suppression may result from slower reaction kinetics or unfavourable equilibria associated with radical formation under extreme pH conditions, ultimately reducing the total amount of hydroxyl radicals produce[23]. In acidic environments, a high proton concentration may lead to the leaching of metal ions or alterations in the catalyst's surface structure, gradually decreasing its photocatalytic efficiency[24]. Conversely, under alkaline conditions, the photocatalyst surface tends to accumulate a negative charge, which can repel negatively charged organic pollutants, thereby reducing their adsorption onto the catalyst surface[25]. Additionally, both highly acidic and alkaline environments may alter the surface structure of the catalyst, potentially leading to the formation of non-reactive surface layers or surface passivation, which limits the availability of active sites for photocatalytic reactions[23]. Furthermore, extreme pH conditions may also accelerate the degradation of the catalyst itself through a process known as photocorrosion. In such cases, reactive oxygen species and radicals formed during photocatalysis can corrode the catalyst surface, reducing its structural stability and long-term activity[26].

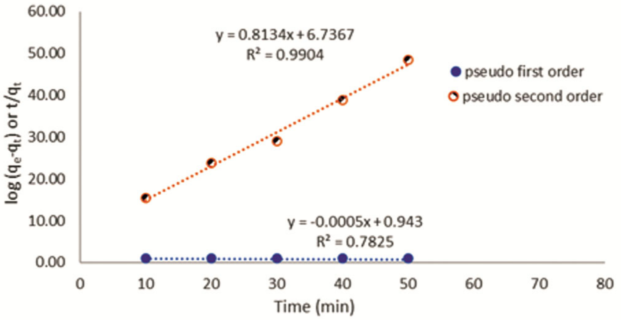

Fig. 5 — Kinetic study of BPA adsorption using the hybrid oxalate-pyrite/chitosan catalyst, analyzed using pseudo-first order and pseudo-second-order kinetic models

Kinetic study

To predict the nature of adsorption and determine the adsorption rate constants, pseudo-first order and pseudo-second-order kinetic models were applied in this study. The rate constants, denoted as k_1 and k_2, were calculated using the kinetic model equations presented as Eq. (3) and Eq. (4), respectively. Plots of log $(q_e - q_t)$ versus time and t/q_t versus time were constructed and are shown in Fig. 5.

Table 1 — Parameters of pseudo first order and pseudo second order kinetic models for the BPA adsorption using hybrid oxalate-pyrite/chitosan

	Pseudo first order			Pseudo second order		
	R^2	k_1 (1/min)	q_e (mg/g)	R^2	k_2 (g/mg.min)	q_e (mg/g)
Adsorption	0.7825	0.0012	8.77	0.9904	0.098	1.229
Photodegradation	0.940	0.05	-	0.945	0.0573	-

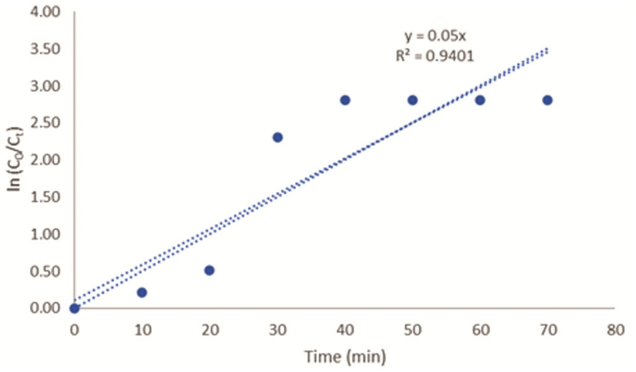

Fig. 6 — Kinetic study of the photocatalytic degradation of BPA using the hybrid oxalate-pyrite/chitosan catalyst, analyzed using the Langmuir–Hinshelwood kinetic model

Both the figure and the kinetic parameters summarized in Table 1 indicate that the pseudo-second-order model best describes the adsorption kinetics of BPA onto the catalyst. Furthermore, the calculated q_e value from the pseudo-second-order model closely matches the experimental q_e, supporting the model's accuracy. This observation agrees with the findings of Cheng *et al.*, who reported that the adsorption of BPA onto chitosan typically follows a pseudo-second-order kinetic model[27]. The kinetic results suggest that the BPA adsorption proceeds via a chemisorption mechanism, indicating that surface adsorption is the rate-limiting step[28]. This behaviour may be attributed to the unique structural characteristics and functional groups present in chitosan, which exhibit strong chemical affinity toward BPA. Specifically, the hydroxyl (–OH) and amino (–NH_2) groups in chitosan enhance BPA adsorption through hydrogen bonding and electrostatic interactions[27]. Additionally, the aromatic structure of BPA—due to its benzene rings—facilitates π–π interactions with chitosan, further improving its adsorption capacity via non-covalent bonding mechanisms[29].

The photodegradation kinetics of BPA using the hybrid oxalate-pyrite/chitosan catalyst were described using the pseudo-first-order model, as illustrated in Fig. 6, which presents the plot of $\ln(C_0/C_t)$ versus time. The high R^2 values indicate that the reaction mechanism closely follows pseudo-first-order kinetics during the photocatalytic degradation process. This finding is consistent with the results reported in the study by Tsai *et al.*, and Bechambi *et al.*, supporting the applicability of the pseudo-first-order model in describing BPA photodegradation under similar conditions[13,30].

Conclusion

The investigation into the photocatalytic degradation of BPA demonstrated a significant enhancement in performance when using the hybrid oxalate-pyrite/chitosan catalyst, achieving a degradation efficiency of 93.89%. In comparison, oxalate-pyrite and chitosan used individually resulted in much lower efficiencies of 14.6% and 17.6%, respectively. The catalyst exhibited optimal performance at an initial BPA concentration of 5 ppm and at neutral pH (pH 7), while variations in catalyst dosage did not significantly influence the degradation efficiency. Kinetic analysis revealed that BPA adsorption occurred via chemisorption, and the photocatalytic degradation followed pseudo-first-order reaction kinetics. While promising activity was observed using the hybrid oxalate-pyrite/chitosan, additional factors such as catalyst reusability, long-term stability, and potential deactivation due to iron leaching or chitosan degradation were not evaluated and will be addressed in future work. Similarly, the influence of light intensity and wavelength, as well as performance in real or complex wastewater matrices are critical aspects for practical deployment and are identified as future research directions. Overall, the findings demonstrate the potential of the oxalate-pyrite/chitosan hybrid catalyst as a low-cost, eco-friendly, and efficient solution for BPA remediation in water. By utilizing naturally abundant materials, operating under visible light, and achieving high degradation efficiency, the catalyst aligns well with the principles of green chemistry, sustainable environmental engineering, and circular resource use. With further optimization and real-world validation, this hybrid system represents a promising prototype for future solar-driven water treatment technologies.

Acknowledgement

The authors would like to thank Universiti Malaysia Pahang Al Sultan Abdullah (UMPSA) for funding this work under Collaborative Research Grant (CRG) [University Reference: RDU192316].

Conflict of interest

The authors declare no conflict of interest.

References

1 Haron D E M, Yoneda M, Hod R, Ramli M R & Aziz M Y, Assessment of 18 endocrine disrupting chemicals in tap water samples from Klang Valley, Malaysia, *Environ Sci Pollut Res*, 30 (2023) 111062.

2 Caliman A F, Teodosiu C & Balasanian I, Applications of heterogeneous photocatalysis for industrial wastewater treatment, *Environ Eng Manag J*, 1 (2002) 187.

3 Ahmed S N & Haider W, Heterogeneous photocatalysis and its potential applications in water and wastewater treatment: A review, *Nanotechnology*, 29 (2018) 342001.

4 Rashid R, Shafiq I, Akhter P, Iqbal M J & Hussain M, A state-of-the-art review on wastewater treatment techniques: The effectiveness of adsorption method, *Environ Sci Pollut Res*, 28 (2021) 9050.

5 Berenstein G, Hughes E A, Zalts A, Basack S, Bonesi S M & Montserrat J M, Environmental fate of dibutylphthalate in agricultural plastics: Photodegradation, migration and ecotoxicological impact on soil, *Chemosphere*, 290 (2022) 133221.

6 Oyim J, Amuhaya E, Matshitse R, Mack J & Nyokong T, Integrated photocatalyst adsorbents based on porphyrin anchored to activated carbon granules for water treatment, *Carbon Trends*, 8 (2022) 100191.

7 Molinari R, Argurio P, Szymański K, Darowna D & Mozia S, Photocatalytic membrane reactors for wastewater treatment, *Curr Trends Future Dev Bio Membr*, (2020) 83.

8 Diao Z H, Xu X R, Liu F M, Sun Y X, Zhang Z W, Sun K F, Wang S Z & Cheng H, Photocatalytic degradation of malachite green by pyrite and its synergism with Cr(VI) reduction: Performance and reaction mechanism, *Sep Purif Technol*, 154 (2015) 168.

9 Tian A, Xu Q, Shi X, Yang H, Xue X, You J, Wang X, Dong C, Yan X & Zhou H, Pyrite nanotube array films as an efficient photocatalyst for degradation of methylene blue and phenol, *RSC Adv*, 5 (2015) 62724.

10 Bhatt P, Joshi S, Urper-Bayram G M, Khati P & Simsek H, Developments and application of chitosan-based adsorbents for wastewater treatments, *Environ Res*, 226 (2023) 115530.

11 Wang J & Zhuang S, Removal of various pollutants from water and wastewater by modified chitosan adsorbents, *Crit Rev Environ Sci Technol*, 47 (2017) 2331.

12 Zulkiefli Q, Vasudevan P, Nor S H M, Tan J A, Abdullah H, Aziz F, Sambudi N S & Rosli A N, Photocatalytic degradation of humic acid on oxalate-pyrite/chitosan, 2907 (2023) 030008.

13 Tsai W T, Lee M K, Su T Y & Chang Y M, Photodegradation of bisphenol: A in a batch TiO_2 suspension reactor, *J Hazard Mater*, 168 (2009) 269.

14 Saheed I O, Da-Oh W & Suah F B M, Chitosan modifications for adsorption of pollutants-A review, *J Hazard Mater*, 408 (2021) 124889.

15 Zhang W, Jiang X, Ralston J, Cao J, Jin X, Sun W & Gao Z, Efficient heterogeneous photodegradation of Eosin Y by oxidized pyrite using the photo-Fenton process, *Miner Eng*, 191 (2023) 107972.

16 Weller C, Horn S & Herrmann H, Photolysis of Fe(III) carboxylato complexes: Fe(II) quantum yields and reaction mechanisms, *J Photochem Photobiol A Chem*, 268 (2013) 24.

17 Pelaez M, Nolan N T, Pillai S C, Seery M K, Falaras P, Kontos A G, Dunlop P S M, Hamilton J W J, Byrne J A, O'Shea K, Entezari M H & Dionysiou D D, A review on the visible light active titanium dioxide photocatalysts for environmental applications, *Appl Catal B Environ*, 125 (2012) 331.

18 Mohamadpour F & Amani A M, Photocatalytic systems: Reactions, mechanism, and applications, *RSC Adv*, 14 (2024) 20609.

19 Shabnum S S, Siranjeevi R, Susmitha R, Raj C K, Nivetha P, Benazir K, Saravanan A & Vickram A S, Enhanced photocatalytic degradation of crystal violet and malachite green oxalate dyes by $NiAg_2O$ infused chitosan nanocomposites, *Int J Biol Macromol*, 286 (2025) 138365.

20 Dariani R S, Esmaeili A, Mortezaali A & Dehghanpour S, Photocatalytic reaction and degradation of methylene blue on TiO_2 nano-sized particles, *Optik (Stuttg)*, 127 (2016) 7143.

21 Khan S U M, Al-Shahry M & Ingler W B, Efficient photochemical water splitting by a chemically modified n-TiO_2, *Science*, 297 (2002) 2243.

22 Hoffmann M R, Martin S T, Choi W & Bahnemann D W, Environmental applications of semiconductor photocatalysis, *Chem Rev*, 95 (1995) 69.

23 Mills A & Le H S, An overview of semiconductor photocatalysis, *J Photochem Photobiol A Chem*, 108 (1997) 1.

24 Pirkanniemi K & Sillanpää M, Heterogeneous water phase catalysis as an environmental application: A review, *Chemosphere*, 48 (2002) 1047.

25 Solís M, Solís A, Pérez H I, Manjarrez N & Flores M, Microbial decolouration of Azo dyes: A review, *Process Biochem*, 47 (2012) 1723.

26 Fujishima A & Honda K, Electrochemical photolysis of water at a semiconductor electrode, *Nature*, 238 (1972) 37.

27 Cheng F & Wang J, Removal of bisphenol a from wastewater by adsorption and membrane separation: Performances and mechanisms, *Chem Eng J*, 484 (2024) 149414.

28 Kasbaji M, Mennani M, Grimi N, Barba F J, Oubenali M, Simirgiotis M J, Mbarki M & Moubarik A, Implementation and physico-chemical characterization of new alkali-modified bio-sorbents for cadmium removal from industrial discharges: Adsorption isotherms and kinetic approaches, *Process Biochem*, 120 (2022) 213.

29 Nicolle L, Journot C M A & Gerber-Lemaire S, Chitosan functionalization: Covalent and non-covalent interactions and their characterization, *Polymers*, 13 (2021) 4118.

30 Bechambi O, Jlaiel L, Najjar W & Sayadi S, Photocatalytic degradation of bisphenol a in the presence of Ce-ZnO: Evolution of kinetics, toxicity and photodegradation mechanism, *Mater Chem Phys*, 173 (2016) 95.