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Photocatalytic Degradation of New Fuchsine using Lead Chromate for Water Reuse: Efficiency and Degradation Pathway Contaminants Remediation

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ABSTRACT

This study investigates a novel property of lead chromate that enhances its effectiveness in degrading organic dye pollutants. This property arises from lead chromate's photocatalytic activity under visible light. Lead chromate samples were prepared using direct co-precipitation. Using the cationic dye New Fuchsine as a model molecule, the catalytic performance of these lead chromate compounds was investigated in order to evaluate their green catalytic activity. In order to assess the lead chromate degradation efficiency, the study looked at a number of experimental parameters, including the pH of the dye solution, contact time, lead chromate dosage, and initial concentration of New Fuchsine dye. Additionally, the study discusses potential mechanisms underlying the breakdown of New Fuchsine facilitated by lead chromate under visible light conditions.

Keywords: Lead chromate,photocatalytic, New fuchsine, Degradation, Visible light, Recyclability.

INTRODUCTION

The swift advancement of diverse manufacturing technologies, including textiles, food production, leather, paper, and printing, significantly improved human living standards. The environment and the health of people and animals on Earth can be harmed by organic dyes in wastewater released by numerous companies, including those that produce food, plastic, and textiles[1]. Industries often discharge residual dyes and other pollutants directly into water bodies, causing pollution. Photocatalysis is one of the most promising methods for breaking down toxic organic pollutants in various industrial effluents[2]. Traditional chemical, biological, and physical wastewater treatment methods can't fully degrade dyes like Rhodamine B into non-polluting compounds. Biological techniques are slow and ineffective for many dyes[3]. Metal oxides, metal sulfides, and oxy halides are common in nature and are employed extensively as photocatalysts on a vast scale. This is because of their ability to produce charge carriers, remarkable longevity throughout several phases, and biocompatibility[4].

Remediating water pollution may benefit from the use of the binary compound $SrAl_2O_4:Eu^{2+}$, $Dy^{3+}/g\text{-}C_3N_4$, which effectively degrades basic fuchsine and exhibits enhanced photocatalytic performance, durability, and reusability[5]. A successful synthesis, analysis, and optimization for basic fuchsine photodegradation, the high-efficiency, recoverable $Ag_2CrO/Ag/FeO/RGO$ photocatalyst (AAFR-NCPs) achieved an 80.15% degradation efficiency under optimal conditions[6].

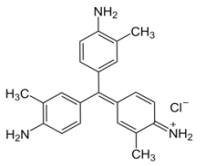
Eco-friendly, inexpensive dye-sensitized solar cells using New Fuchsine dye, an aqueous electrolyte, and counter electrodes that are free of platinum[7]. The use of graphene quantum dots as innovative and eco-friendly nanomaterials for the breakdown of cationic dyes by Photocatalysis, including New Fuchsine, under visible light[8]. Electrospun, self-assembled ZnO nanofiber structures to achieve photocatalytic degradation of acid fuchsine dye under natural solar radiation[9].

A novel recoverable catalyst, the $CoCr_2O_4$@ GeO_2@ZnO core-shell nanoparticle, was prepared, characterized, and used for the photocatalytic degradation of basic fuchsine dye[10]. A simple one-pot solid-state method to fabricate a novel binary nanocomposite of commercial ZnO and $PbCrO_4$ demonstrated enhanced photocatalytic degradation of Rhodamine B dye[11]. The sonophotocatalytic treatment of rhodamine B using a visible-light-driven composite of CeO_2/ Ag_2CrO_4 in batch mode. The CeO_2 nanofibers, synthesized via electrospinning into ribbon-like structures, were a crucial component in their study[12]. A straightforward synthesis of $PbCrO_4$ and $PbCrO_4$/Ag nanostructures, demonstrating their effectiveness as photocatalysts for degrading organic contaminants[13]. The use of commercial $PbCrO_4/TiO_2$ for the photodegradation of rhodamine B in aqueous solutions caused by visible light[14].

The GO/ZnO nanocomposite, synthesized via sol-gel, effectively degrades BF dye, enhancing ZnO's photocatalytic efficiency by reducing its band gap[15]. Nano-lead chromate ($PbCrO_4$) via chemical precipitation to address water-soluble Cr(VI) leaching from COPR through simple water washing. They utilized this material for degrading methylene blue (MB)[16].

In international scientific notation, 4-[(4-amino-3-methylphenyl) (4-imino-3-methylcyclohexa-2, 5-dien-1-ylidene) methyl]-2-methylaniline hydrochloride is known as New Fuchsine. It's chemical formula is C=H=ClN=, and it has a molar mass of 365.91 g/mol, as shown in Table 1. New Fuchsine, a water-soluble, odorless, dark green powder, is used as a cationic dye and redox indicator. This study investigates $PbCrO_4$'s photocatalytic efficacy in degrading it.

Table 1. The composition and properties of the dye

Names	Magenta III, Basic Violet 2, New Fuchsine, New Magenta, Fuchsine NB
Composition	
λ_{max}(nm)	546nm
MW(g mol^{-1})	365.91

EXPERIMENTAL

Materials and Reagents

Lead chromate was created by co-precipitating it with potassium chromate and water-soluble lead nitrate in a wet chemical procedure. Distilled water was added to separate beakers of 27.60 g of lead nitrate and 16.182 g of potassium chromate. When potassium chromate and lead nitrate solutions are combined, precipitates of lead chromate with a profound lemon-yellow hue result. It was then filtered, thoroughly rinsed in water, and baked at 100°C. Photocatalytic process.

The degradation rate of New Fuchsine dye served as a measure of the catalyst's photocatalytic performance. To prepare a stock solution of the dye at 1.0 x 10^{-3} M concentration, In 250 milliliters of double distilled water, 0.0914 g of the dye was dissolved. Using a digital pH meter (Systronics model 335), the pH of the dye solution was checked, and any necessary corrections were performed with standard solutions of 0.1 N hydrochloric acid or 0.1 N sodium hydroxide. Every ten minutes, 3mL of the reaction mixture containing 0.10 g of photocatalyst was removed for examination under the light of a 200W tungsten lamp.

Absorbance (A) at λ_{max} = 546nm was measured, with thermal radiation blocked by a water filter. The light source and reaction mixture's distance were changed based on the light intensity, which was measured with a Suryamapi (CEL model SM

201). We measured the absorbance of the solution at different time intervals using a spectrophotometer (Systronics Model 106). The results showed that absorbance decreased with increased exposure time, indicating a reduction in the concentration of New Fuchsine dye over time.

RESULTS AND DISCUSSION

The following equation was used to get the rate constant:

$K = [2.303 \times slope]$

Typical Run

Figure 1 shows a graphic representation of the usual run, with a rate constant of 1.18×10^{-4} s^{-1}. Light intensity = 70.0 $mWcm^{-2}$, pH = 8.0, [New Fuchsine] = 1.8×10^{-5} M, Semiconductor = 0.04 gram.

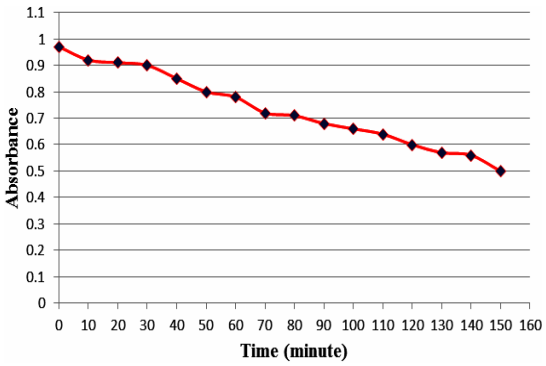


Fig. 1. Typical run

Effect of parameters

pH Variation

The photocatalytic degradation rate of New Fuchsine increases with the rise in pH, reaching its peak at pH = 8.0. Beyond this point, the reaction rate decreases. This behavior is due to the enhanced generation of oxygen anion radicals ($O2^{\bullet-}$) with increasing pH, as these radicals are formed when O_2 molecules react with electrons (e^-) in the semiconductor's conduction band. Superoxide anion radicals can further react with protons to produce $HO_2^{\bullet}$ radicals most effectively generated in primary conditions. The presence of more $HO_2^{\bullet}$ radicals accelerates the photocatalytic degradation of the dye. However, above pH = 8.0, the rate declines because the neutralization of New Fuchsine reduces its cationic form, leading to less adsorption of -OH ions and diminished attraction to the negatively charged semiconductor surface. This relationship can be illustrated in Figure 2.

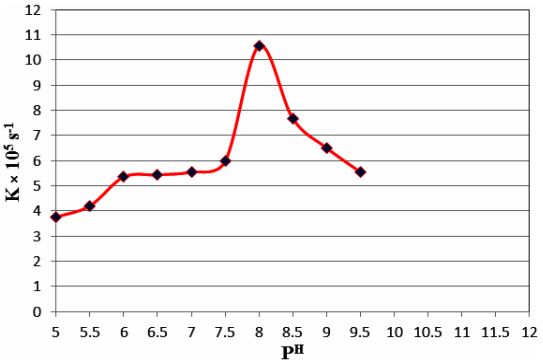


Fig. 2. pH Variations

The [New Fuchsine] value is 1.8×10^{-5} M, the semiconductor weighs 0.04 g, and the light intensity is 70.0 $mWcm^{-2}$.

Dye Concentration Variation

Figure 3 presents the findings regarding the impact of dye concentration on the photocatalytic degradation of New Fuchsine, investigated within the range of 1.0×10^{-5} to 2.4×10^{-5} M. However, at approximately 1.8×10^{-5} M (the optimal condition), photocatalytic degradation efficiency started to decline. As dye concentration was raised, it was noticed that dye degradation increased. In this situation, the dye will begin to function as an internal filter, preventing the intended.

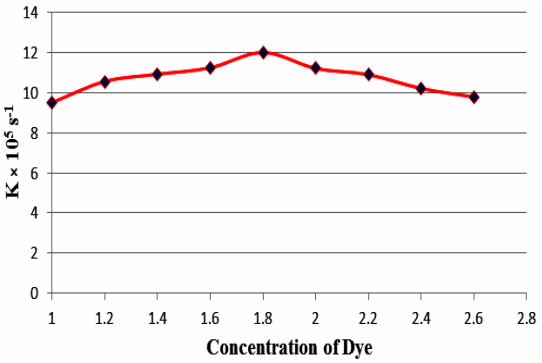


Fig. 3. Concentration of Dye Variation

Composite Variation

The study explored the effect of varying catalyst amounts (between 0.02 and 0.18 g) on the rate at which dyes deteriorate. Fig. 4 illustrates how the rate constant varies with different semiconductor quantities. It was observed that increasing the amount of photocatalyst enhances the rate of photocatalytic activity. Specifically, a semiconductor dosage of 0.04 g resulted in the highest degradation rate. However,

beyond 0.04 g, the rate significantly dropped constantly. This decline is likely due to the increased thickness of the photocatalyst layer rather than an increase in exposed surface area, as evidenced by experiments using vessels of different dimensions.

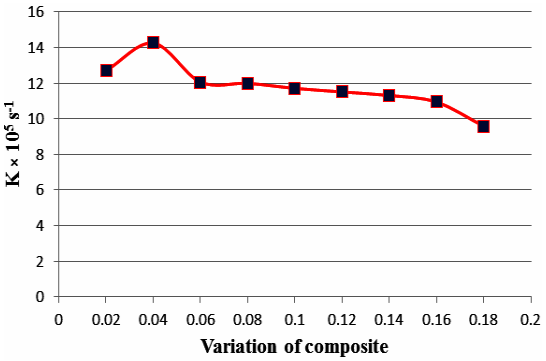


Fig. 4. Variation of Composite

This decrease may also be attributed to potential light obstruction caused by excessive amounts of photocatalyst. The experimental conditions were pH = 8.0, [New Fuchsine] = 1.8×10^{-5} M, and 70.0 $mWcm^{-2}$ is the light intensity.

Light Intensity Variation

To investigate how light intensity affects photocatalytic degradation, distances ranging from 20.0 to 70.0 $mWcm^{-2}$ were retained in the space between the photocatalyst's exposed surface and the light source. Fig. 5 depicts rate constants at various light intensities. It was shown that New Fuchsine's photocatalytic degradation depended more on increasing light intensity because more photons will strike a given area of the photocatalyst surface in a given amount of time. The highest degradation rate of New Fuchsine was noted at 70.0 $mWcm^{-2}$. This could be attributed to thermal effects or secondary reactions. pH = 8.0, [New Fuchsine] = 1.8×10^{-5} M, Semiconductor = 0.04 gram.

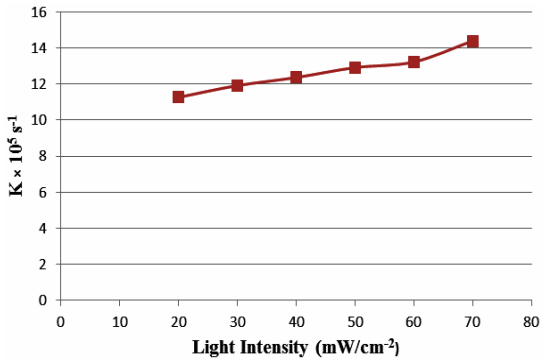


Fig. 5. Variation of Light Intensity

Mechanism

On the basis of these findings, the following basic mechanism for the photocatalytic degradation of New Fuchsine dye has been proposed:

$$^1NF_0 \xrightarrow{h\nu} {}^1NF_1$$

$$^1NF_1 \xrightarrow{ISC} {}^3NF_1$$

$$SC \longrightarrow e^- (CB) + h+ (VB)$$

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

$$^-OH + H^+ \longrightarrow HO.$$

$$HO^{\cdot} + {}_3NF_1 \longrightarrow \text{Leuco NF}$$

$$\text{Products} \longrightarrow \text{Leuco NF}$$

New Fuchsine absorbs radiation at the appropriate wavelength, becoming excited and reaching its first excited singlet state. To get to a more stable triplet state, it also goes through intersystem crossover (ISC). This energy is simultaneously used by the semiconductor lead chromate (SC) to promote an electron from the valence band to the conduction band. Dissolved oxygen in the medium abstracts this electron, forming a superoxide anion radical ($O_2^{\bullet -}$). In the primary environment, this anion radical combines with a proton to generate $HO_2^{\bullet}$ radicals. $HO_2^{\bullet}$ radicals oxidize. New Fuchsine may further break down into end products in its leuco state. Surprisingly, the hydroxyl radical scavenger 2-propanol did not considerably alter the rate of New Fuchsine degradation, suggesting that the OH radical is not actively involved as an oxidizing species in this process.

Scavenger test

In this study, several scavengers, such as p-benzoquinone (BQ) for $O_2^{\bullet -}$, isopropyl alcohol (IPA) for •OH, and potassium iodide (KI), were employed. Fig. 6 clearly shows that all scavengers contributed to reducing the degradation of New Fuchsine dye to some extent. Specifically, the degradation of New Fuchsine decreased by 25%, 8%, and 22% in the presence of p-benzoquinone (BQ), KI, and IPA, respectively. These findings from different quenchers suggest that •OH contributes significantly to the New Fuchsine's photocatalytic breakdown.

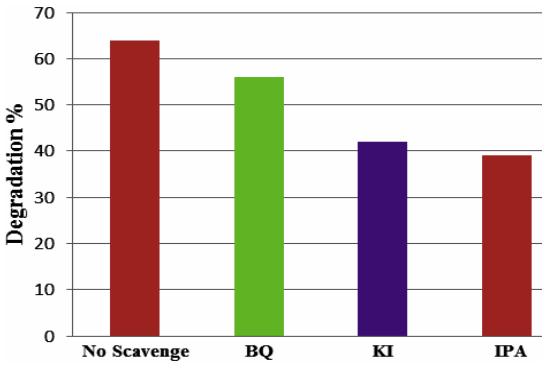


Fig. 6. Scavenger test with degradation

Stability and reusability of Lead Chromate

Four consecutive photocatalytic experimental runs using recycled Lead Chromate photocatalyst and New Fuchsine solutions were conducted to assess the reusability of Lead Chromate. Up to four rounds of the New Fuchsine's breakdown by Lead Chromate particles' activity were noted. By employing the same batch of lead chromate catalyst in subsequent tests to degrade new fuchsine, $PbCrO_4$'s stability and reusability are assessed. According to Fig. 7, the New Fuchsine photodegradation efficiency was 64% on the first run and 48% on the fourth run. The minor drop in effectiveness indicated that synthetic $PbCrO_4$ would be a suitable catalyst for use in real-world applications.

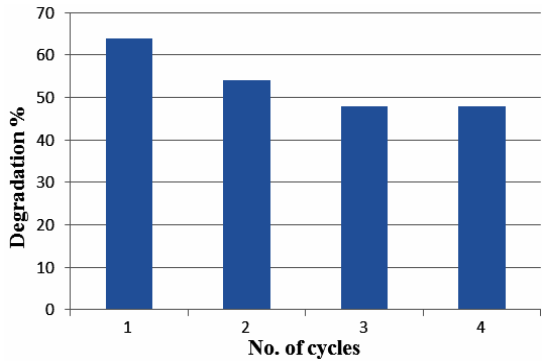


Fig. 7. Stability and Reusability

CONCLUSION

Lead Chromate was successfully synthesized and tested for its effectiveness in degrading New Fuchsine dye under visible light. The optimal conditions for this photocatalytic process were determined to be a light intensity of 70.0 mW/cm², a pH level of 8.0, a dye concentration of 1.8×10^{-5} M, and 0.04 g of the semiconductor. The study demonstrated that Lead Chromate maintained its photocatalytic efficiency over four cycles of reuse, with no significant decrease in activity, as illustrated in Figure 8.

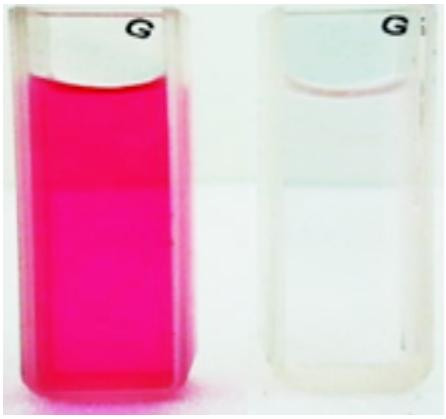


Fig. 8. Practical Setup

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Conflicts of Interest

No conflicts of interest are disclosed by the authors.

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