AKTA KIMIA
INDONESIA

Akta Kimindo Vol. 11(1), 2026: 53-62

Electrochemical Degradation of Remazol Black B Using Carbon Electrode

Muh. Supwatul Hakim[1*], Stevin Carolius Angga[1,2], Mokhamat Ariefin[1], and Riandy Putra[1]

[1] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Palangka Raya, Palangka Raya, Indonesia 73111
[2]Center for Development of Science, Technology and Peatland Innovation (PPIIG), Universitas Palangka Raya, Indonesia

** Corresponding author: hakim@mipa.upr.ac.id*

Abstract

The presence of dye-containing wastewater in the environment poses significant risks to both ecosystems and human health. This study aimed to investigate the utilization of carbon electrodes derived from battery waste for the electrochemical degradation of Remazol Black B (RBB), determine the effect voltage, electrolysis time, and evaluate the degradation performance. Electrochemical degradation experiments were conducted using recycled carbon electrodes obtained from battery waste, while the effects of voltage and electrolysis time on decolorization efficiency were monitored using a UV–Vis spectrophotometer. The results showed that the optimum degradation conditions were achieved at voltage of 15 V and an electrolysis time of 20 min, resulting in 100% decolorization efficiency. At lower voltages, decolorization efficiencies of 70% and 100% were obtained at 5 V for 60 min and 10 V for 30 min, respectively. These findings demonstrate that carbon electrodes from battery waste can serve as an effective and sustainable alternative electrode material for dye wastewater treatment, offering comparable performance while promoting the valorization of waste materials.

Keyword: *Remazol black B, Carbon electrode, Electro-oxidation.*

Abstrak

Keberadaan air limbah yang mengandung zat warna di lingkungan menimbulkan risiko signifikan bagi ekosistem dan kesehatan manusia. Studi ini bertujuan untuk mempelajari pemanfaatan elektroda karbon yang berasal dari limbah baterai untuk degradasi elektrokimia Remazol Black B (RBB), menentukan pengaruh tegangan, waktu elektrolisis, dan mengevaluasi kinerja degradasi. Degradasi secara elektrokimia telah dilakukan menggunakan elektroda karbon yang diperoleh dari limbah baterai, sementara pengaruh

tegangan dan waktu elektrolisis terhadap efisiensi dekolorisasi diamati menggunakan spektrofotometer UV-Vis. Hasil menunjukkan bahwa kondisi degradasi optimal dicapai pada tegangan 15 V dan waktu elektrolisis 20 menit, menghasilkan efisiensi dekolorisasi 100%. Pada tegangan yang lebih rendah, efisiensi dekolorisasi sebesar 70% dan 100% diperoleh masing-masing pada 5 V selama 60 menit dan 10 V selama 30 menit. Temuan ini menunjukkan bahwa elektroda karbon dari limbah baterai dapat berfungsi sebagai bahan elektroda alternatif yang efektif dan berkelanjutan untuk pengolahan air limbah zat warna, menawarkan kinerja yang sebanding sekaligus mendorong pemanfaatan bahan limbah.

Kata Kunci: Remazol black B, Elektroda karbon, Elektro-oksidasi.

I. INTRODUCTION

Currently, more than 100,000 types of dyes are produced worldwide, and textile industry waste is a major contributor to water pollution [1]. As an export commodity, this industry has caused serious environmental problems related to the use of dyes from the dyeing and finishing processes, which are disposed of along with wastewater. One of the dyes often used in the production of 'Batik Benang Bintik' is Remazol Black B (RBB). RBB is a dye commonly used in the batik industry and belongs to the azo reactive dyes, which have azo (-N=N-) and sulfonate ($-SO_3-$) groups in their molecular structure, acting as the main chromophores that produce intense black colors [2]. However, the reduction of azo (-N=N-) bond will produce compounds (amine) that are more toxic than the original compounds [3]. Therefore, RBB waste treatment is crucial before discharging it into the environment.

Various methods of reducing dye waste have been developed, including the adsorption method [4]. This method has been ineffective because the adsorbed dyes still accumulate in the adsorbent, which will eventually cause new problems. Other methods, such as photodegradation using photocatalysts and ultraviolet radiation, can break down dyes into simpler components that are safer for the environment [5], but this process requires high energy and is relatively expensive. Wastewater treatment involving the use of microorganisms, particularly bacteria, to decompose organic substances and dyes in batik wastewater [6]. This process requires a long time and high cost to isolate suitable bacteria. Several wastewater treatment methods have various disadvantages and still need to be developed for dye waste treatment effectively and efficiently.

The electrochemical method is an environmentally friendly, practical, inexpensive, efficient, and does not cause

sludge production in the degradation of dye waste. In the electrochemical method, hydroxyl radicals (•OH) are generated on the anode surface through the direct oxidation of water, and the dye waste reacts with the hydroxyl radicals (•OH) and degrades the organic material into CO_2 and H_2O [7]. Previous studies have reported decolorization of RBB dye using a modified Fenton process with PbO_2 electrodes and 10% H_2O_2 [8], graphite/NiO/Ni electrode [9], SiO_2/NiO/Ni electrode [10], Novel Sb-doped SnO_2 ceramic electrodes [11], and PbO_2 with Na_2SO_4 as electrolyte [12]. However, the use of H_2O_2 as an electrolyte can cause toxic effects, and the fabrication of the electrode shows a complex and expensive synthesis process.

In this work, we have utilized carbon electrodes obtained from battery waste as electrodes in the electro-oxidation process of RBB dye waste, which is low-cost, easy, and practical. We have also investigated the effect of voltage and time on the electro-oxidation of RBB and analyzed the decolorization efficiency.

II. MATERIALS AND METHODS

2.1. Materials

The materials used for the investigation include carbon electrodes from battery waste, salt solutions (NaCl > 94%), Remazol Black B (purchased from the local market, CV. Bumbu Batik Utama, Solo), a DC Power Supply (Zhaoxin KXN3010D), and distilled water. Spectrophotometer UV-Vis (Safas Monaco SP2000) was used to determine the absorbance of the solutions.

2.2. Experimental Methodology

Carbon electrodes were manually removed from battery waste, then cleaned using detergent and rinsed with distilled water. The electrodes (anode and cathode) were placed in a beaker with distance of 2 cm. Both electrodes were 50 mm in length and 4 mm in diameter. Then, 100 mL of RBB solution at a concentration of 50 mg/L was mixed with 10 mL of 1% (w/v) salt solution, the schematic cell is shown in Figure 1. Electro-oxidation was carried out using a DC power supply with varying voltages of 5, 10, and 15 V for 60 minutes and each time variation the absorbance value has been measured and analyzed. The maximum wavelength of RBB was examined by measuring the absorbance at 200-800 nm by using UV-Vis spectrophotometer. The decolorization efficiency (DE) was calculated by following the Equation (1) [9]:

$$\text{DE}\ (\%) = \frac{A_0 - A_t}{A_0}\ x100\% \qquad (1)$$

where A_0 is the initial absorbance value from RBB before electro-oxidation, and A_t is the absorbance value after electro-oxidation.

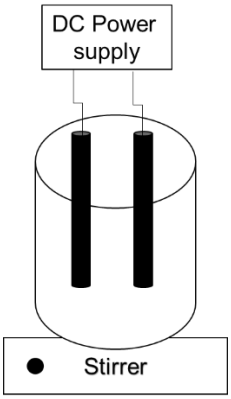

Figure 1. The electro-oxidation schematic cell.

III. RESULTS AND DISCUSSION

3.1. Electro-oxidation process of RBB

The electrochemical process of RBB dye using carbon electrodes in NaCl electrolyte occurs direct and indirect ways. Directly, this process was achieved through the formation of hydroxyl radicals resulting from the oxidation of water, as shown in Equations (2) and (3) below [10]:

$$M + H_2O \rightarrow M(\cdot OH)_n + nH^+ + ne^- \quad (2)$$

$$R + M(\cdot OH) \rightarrow M + Oxidation\ products\ (CO_2) + nH^+ + ne^- \quad (3)$$

Indirect removal occurs due to the degradation of NaCl solution by Cl_2, HClO, or OCl^- ions, depending on the pH, starting with the oxidation of Cl^- ions (Equation 4), followed by reactions (5), (6), and (7):

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (4)$$

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (5)$$

$$HOCl \rightarrow H^+ + OCl^- \quad (6)$$

$$Dye\ waste + OCl^- \rightarrow CO_2 + H_2O + Cl^- \quad (7)$$

3.2. The effect of voltage and time

Figure 2A shows the absorbance spectra during the electrooxidation of RBB dye using 5 V for 60 minutes. At the peak of 598 nm, there was a decrease in absorbance as the electrooxidation time increased. This indicates the occurrence of azo chromophore group cleavage in the RBB compound. A decrease in absorbance also occurred in the ultraviolet region (200-350 nm), indicating oxidation in aromatic rings such as benzene. However, in this process, the formation of oxidants is still limited, resulting in a long oxidation process. Figure 2B shows the level of decolorization efficiency, which occurs gradually from 15% at 5 minutes to 70% at 60 minutes. The lower degradation efficiency observed under these conditions may be attributed to the relatively slow oxidation process, which is associated with the incomplete formation of oxidizing species at the electrode surface.

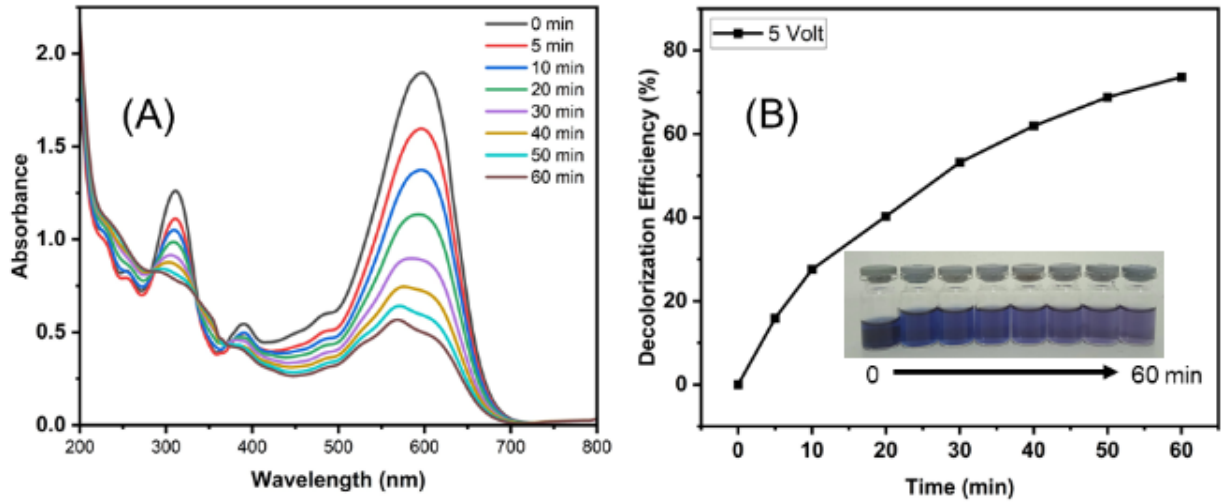

Figure 2. UV-Visible spectra of remazol black B before and after electrooxidation at 5 V (A), and the decolorization efficiency of RBB at visible regions (B).

Electro-oxidation of RBB at a voltage of 10 V is shown in Figure 3. Figure 3A shows that the decrease in absorbance is faster than at 5 V. The color intensity of the solution decreases, and the peak absorbance at the chromophore group has also completely disappeared. In the ultraviolet region, the absorbance values decreased due to oxidation, which breaks the azo bonds and the aromatic structure. Figure 3B shows that the decolorization efficiency increases sharply, reaching approximately 95% at 20 minutes and 100% at 30 minutes. The increase in voltage can accelerate the oxidation reaction of Cl^- ions to Cl_2, which then reacts with water to produce active oxidants (HOCl and OCl^-). In addition, hydroxyl radicals (•OH) formed from the oxidation of water on the anode surface play an important role in the direct oxidation reaction of RBB molecules. The oxidation process at 10 V produces high efficiency in a short time, indicating conditions that are close to optimal between degradation rate and energy consumption.

Figure 4 shows the electrooxidation of RBB using 15 V. The absorbance in the visible region was decreased sharply, indicating the azo group was completely removed. A decrease in absorbance also occurs in the ultraviolet region, which contains aromatic rings (Figure 4A). Decolorization efficiency reaches 100% in 20 minutes. This is because an increase in voltage accelerates the formation of oxidizing species such as HOCl, OCl^-, and OH radicals, which occur directly and indirectly. However, some study reported that the use of high voltage can increase consumption and accelerate electrode

corrosion and produce toxic compounds, especially chlorate (ClO_3^-) and perchlorate (ClO_4^-) [13]. Therefore, optimization is necessary even though it has high efficiency in RBB waste removal.

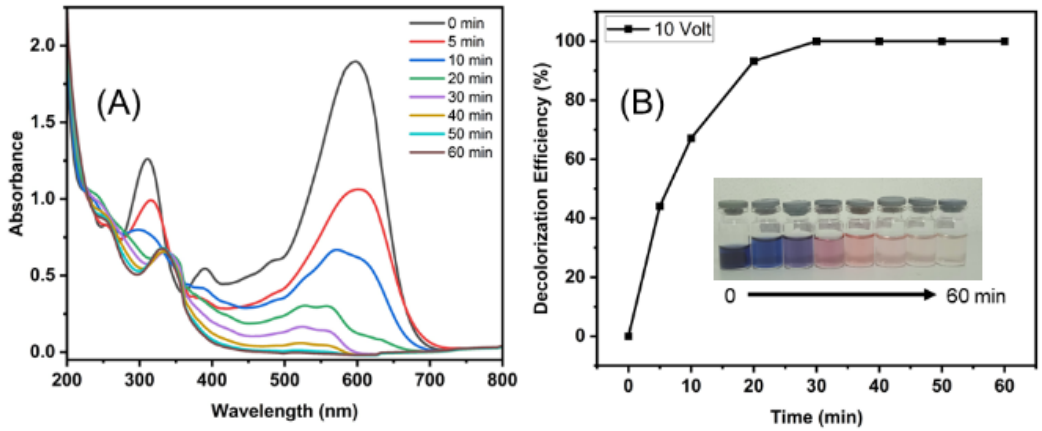

Figure 3. UV-Visible spectra of remazol black B before and after electrooxidation at 10 V (A), and the decolorization efficiency of RBB at visible regions (B).

As shown in Table 1, the carbon electrode derived from battery waste achieved complete decolorization of RBB (100%) within 20 min, which is shorter than the treatment times reported for graphite/NiO/Ni, SiO_2/NiO/Ni composite, graphite, and BDD/Ti-Pt electrodes. The variation in degradation performance can be attributed to differences in electrode properties, including surface area, catalytic activity, oxygen evolution potential (OEP), and the dominant oxidation mechanism. Modified graphite electrodes, such as graphite/NiO/Ni and SiO_2/NiO/Ni composites, generally exhibit enhanced catalytic activity due to the presence of metal oxides that promote the generation of reactive oxidative species. However, the fabrication process of these composite electrodes is relatively complex and often requires additional synthesis steps and precursor materials. In contrast, the carbon electrode prepared from battery waste can be obtained through a simpler and more cost-effective approach while maintaining excellent degradation performance.

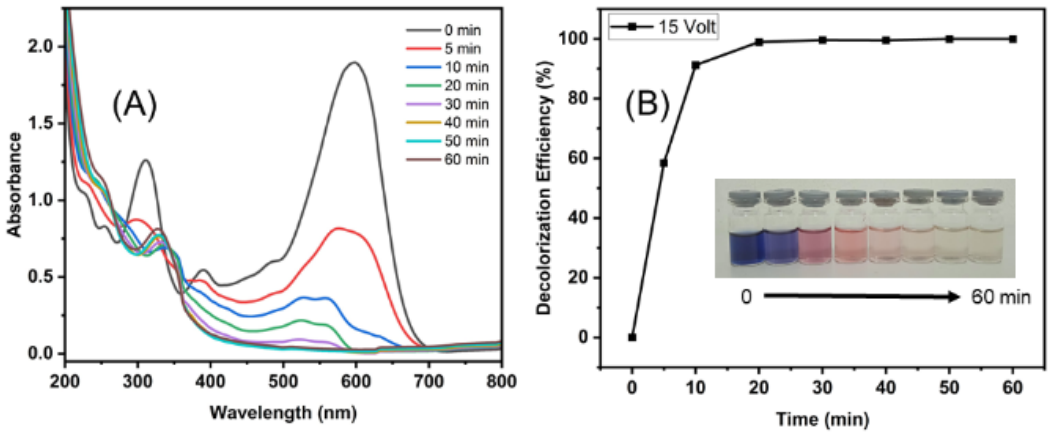

Figure 4. UV-Visible spectra of remazol black B before and after electrooxidation at 5 V (A), and the decolorization efficiency of RBB at visible regions (B).

The FeS electrode also achieved complete decolorization within a relatively short treatment time (25 min), which may be associated with the contribution of iron species in promoting electrochemical oxidation processes. Nevertheless, metal-based electrodes may experience corrosion or gradual metal dissolution during prolonged operation, potentially affecting their long-term stability. Meanwhile, the BDD/Ti-Pt electrode is widely recognized as one of the most effective materials for electrochemical wastewater treatment due to its high oxygen evolution potential and ability to generate large amounts of hydroxyl radicals. Despite these advantages, its practical application is often limited by the high fabrication and operational costs. Compared with these advanced electrode materials, the carbon electrode from battery waste offers a favorable balance between degradation efficiency, treatment time, material availability, and production cost.

In addition, the electrolyte employed may also influence the degradation efficiency. Most previous studies used NaCl or K_2SO_4 as supporting electrolytes, which can affect the formation of reactive oxidizing species and consequently alter the degradation pathway. In the present study, complete decolorization was achieved using a simple salt electrolyte, demonstrating that the recycled carbon electrode was capable of generating sufficient oxidizing species for efficient RBB degradation. These findings highlight the potential of battery-waste-derived carbon electrodes as a low-cost, environmentally friendly, and scalable alternative for the treatment of dye-containing wastewater.

Table 1. Electrochemical degradation of RBB using various electrodes has been reported in previous research.

No	Method	Electrode material	Voltage (V)	Electrolyte	[RBB] (mg/L)	Efficiency (%)	Time (min)	Ref
1	Electrochemical	Graphite/NiO /Ni electrode	9	NaCl	100	100	45	[9]
2	Electrochemical	SiO_2/NiO/Ni composite	9	NaCl	100	100	60	[10]
3	Electrochemical	Graphite	9	NaCl	100	99,74	60	[10]
4	Electrochemical	Fe.S electrode	*	NaCl	50	100	25	[14]
5	Electrochemical	BDD/Ti-Pt	*	K_2SO_4	50	100	180	[15]
6	Electrochemical	Carbon electrode from battery waste	15	Salt	50	100	20	This work

*= not mentioned

IV. CONCLUSION

The electrochemical degradation of Remazol Black B (RBB) dye was successfully carried out using carbon electrodes derived from battery waste. The results showed that the decolorization efficiency increased with increasing applied voltage. Decolorization efficiencies of 70% and 100% were achieved at 5 V for 60 min and 10 V for 30 min, respectively, while complete decolorization was also obtained at 15 V within a shorter treatment time of 20 min. These findings indicate that carbon electrodes recovered from battery waste are effective for the electrochemical treatment of dye-containing wastewater and can serve as a low-cost and sustainable alternative to conventional electrode materials. The main novelty of this study lies in the valorization of battery waste as a functional electrode material, providing a sustainable approach for both waste recycling and wastewater remediation.

However, this study was limited to a single RBB concentration and one electrolyte system, and the degradation performance was evaluated primarily based on decolorization efficiency. Therefore, further investigations are needed including COD and TOC analysis, identifying degradation by-products, and electrode stability.

V. ACKNOWLEDGEMENTS

This work was supported by LPPM Universitas Palangka Raya through 'Hibah Penelitian Dosen Pemula' under contract number: 1451/UN24.13/AL.04/2025.

REFERENCES

[1] P. Thepwat *et al.*, "The synthesis and study of carboxymethyl cellulose from water hyacinth biomass stabilized silver nanoparticles for a colorimetric detection sensor of Hg(II) ions," *RSC Adv.*, vol. 15, no. 49, pp. 41241–41252, Oct. 2025, doi: 10.1039/D5RA04757A.

[2] Y. S. Ayu and R. S. Kasiamdari, "Screening and identification of fungi isolated from batik wastewaters for decolorization of Remazol Black B dye and batik effluent," *J. Degrad. Min. Lands Manag.*, vol. 10, no. 1, pp. 3829–3839, 2022, doi: https://doi.org/10.15243/jdmlm.2022.101.3829.

[3] D. Jager, D. Kupka, M. Vaclavikova, L. Ivanicova, and G. Gallios, "Degradation of Reactive Black 5 by electrochemical oxidation," *Chemosphere*, vol. 190, pp. 405–416, Jan. 2018, doi: 10.1016/j.chemosphere.2017.09.126.

[4] A. A. Hambisa, M. B. Regasa, H. G. Ejigu, and C. B. Senbeto, "Adsorption studies of methyl orange dye removal from aqueous solution using Anchote peel-based agricultural waste adsorbent," *Appl. Water Sci.*, vol. 13, no. 1, p. 24, Jan. 2023, doi: 10.1007/s13201-022-01832-y.

[5] R. Nurillahi, D. N. Halimah, D. G. Apriliani, and I. Fatimah, "Pengolahan Limbah Batik Cair Menggunakan Fotokatalis TiO_2-Abu Vulkanik Desa Wukirsari Yogyakarta," *Khazanah J. Mhs.*, vol. 10, no. 2, pp. 1–8, 2018, doi: 10.20885/khazanah.vol10.iss2.art3.

[6] H. Ariadi, L. Linayati, and T. Y. Mardiana, "Pengaruh Bakteri Indigenous dalam Degradasi Senyawa Fisika Kimia Limbah Batik dan Tekstil," *J. Litbang Kota Pekalongan*, vol. 20, no. 2, pp. 168–175, 2022, doi: 10.54911/litbang.v20i2.218.

[7] P. V. Nidheesh, M. Zhou, and M. A. Oturan, "An overview on the removal of synthetic dyes from water by electrochemical advanced oxidation processes," *Chemosphere*, vol. 197, pp. 210–227, Apr. 2018, doi: 10.1016/j.chemosphere.2017.12.195.

[8] M. A. Hasibuan, D. S. Widodo, and R. A. Lusiana, "Decolorization of Remazol Black B Solution by PbO_2 Modified Fenton Method in a Scaled Up Reactor," *J. Kim. Sains dan Apl.*, vol. 21, no. 2, pp. 59–63, 2018, doi: 10.14710/jksa.21.2.59-63.

[9] N. M. Wiratini, T. Triyono, W. Trisunaryanti, and A. Kuncaka, "Graphite/NiO/Ni electrode for electro-oxidation of the remazol black 5 dye,"

Bull. Chem. React. Eng. Catal., vol. 16, no. 4, pp. 847–856, 2021, doi: 10.9767/bcrec.16.4.11702.847-856.

[10] N. M. Wiratini, W. Trisunaryanti, Triyono, and A. Kuncaka, "Electrochemical Removal of Remazol Black 5 (RB-5) Using SiO_2/NiO/Ni Nanocomposite Electrocatalyst Deposited on the Surface of Graphite Electrodes," *Evergreen*, vol. 10, no. 3, pp. 1274–1285, 2023, doi: 10.5109/7151673.

[11] T. Droguett *et al.*, "Electrochemical Degradation of Reactive Black 5 using two-different reactor configuration," *Sci. Rep.*, vol. 10, no. 1, p. 4482, Mar. 2020, doi: 10.1038/s41598-020-61501-5.

[12] D. Setiyo, L. Suyati, and A. Haris, "Decolorization of Artificial Waste Remazol Black B using Electrogenerated Reactive Spesies," *J. Sains dan Apl.*, vol. 21, no. 1, pp. 29–33, 2018.

[13] L. Wang, Y. Wang, Y. Sui, J. Lu, B. Hu, and Q. Huang, "Formation of chlorate and perchlorate during electrochemical oxidation by Magnéli phase Ti_4O_7 anode: inhibitory effects of coexisting constituents," *Sci. Rep.*, vol. 12, no. 1, pp. 1–8, 2022, doi: 10.1038/s41598-022-19310-5.

[14] N. A. Azizan, N. Nasuha, and H. I. Maarof, "Degradation of Reactive Black 5 Dye (RB5) using Iron Electrode (Fe.S) Derived from Iron Sludge Steel Waste via Electrochemical Method," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1216, no. 1, 2023, doi: 10.1088/1755-1315/1216/1/012037.

[15] V. M. Vasconcelos *et al.*, "Electrochemical removal of Reactive Black 5 azo dye using non-commercial boron-doped diamond film anodes," *Electrochim. Acta*, vol. 178, pp. 484–493, Oct. 2015, doi: 10.1016/j.electacta.2015.07.133.