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Research Paper

Selective Adsorption of Anionic Dyes by Graphene Oxide Adsorbent

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Abstract
Pollution from dyes is well-known for its harmful effects on human health and the environment. Eliminating pollutants such as dyes is a crucial task that can be achieved through various methods, one of which is adsorption. The synthesis of graphene oxide material is achieved from graphite using the Hummers method. The obtained material was then characterised using XRD and FT-IR techniques and tested as an adsorbent for selective adsorption of anionic dyes. The obtained results indicate that the congo red dye was absorbed the most in the selective dyes process, followed by the methyl orange dye, and finally the direct yellow dye.

Keywords
Selective Adsorption, Graphene Oxide, Anionic Dyes

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1. INTRODUCTION

As the economy continues to grow, the issue of environmental pollution is increasingly concerning, leading to stricter regulations on pollution emissions. Industrial pollutants often include dyes, which are frequently encountered. Synthetic dyes are aromatic organic compounds known for their durability, resistance to biodegradation, and long-lasting nature (Ji et al., 2024). Studies have shown that organic synthetic dyes possess strong chemical stability and can be harmful to living organisms due to their low (Arunkumar et al., 2024; Chinoune et al., 2024; Yan et al., 2024). Hence, the presence of organic dyes presents a significant risk to both human well-being and the natural surroundings. Certain dyes possess properties that can be harmful to health, including carcinogenic, mutagenic, and teratogenic effects, even when present in low concentrations (Arunkumar et al., 2024).

Synthetic dyes have found extensive applications across diverse industries such as textile, paper manufacturing, cosmetics, plastics, and food sectors (Shi et al., 2022; Wang et al., 2024). Unlike natural dyes that are typically extracted from plants, synthetic dyes are produced using organic molecules as their initial components (Shi et al., 2022). Dyes can be classified into three distinct categories according to their charge: cationic dyes, anionic dyes, and amphoteric ionic dyes. Separating the different types of dye molecules in wastewater can be a challenging task due to their varying compositions (Wang et al., 2024).

Various strategies have been developed to eliminate and break down organic dyes in wastewater, such as membrane separation, ion exchange, coagulation, chemical oxidation, and adsorption (Ahmad et al., 2023; Amri et al., 2023; Guo et al., 2024; Tian et al., 2024; Yuan et al., 2024). Among various techniques, the adsorption technique has garnered greater attention due to its low initial cost, ability to reuse the adsorbent multiple times, simplicity, affordability, and ease of operation (Fu et al., 2024; Siregar et al., 2022; Umesh et al., 2024; Yuan and Lu, 2024).

In wastewater containing dyes, the dyes are commonly found in a blend of different hues, which vary based on the factory's production timetable. An approach to process these different dye components involves their simultaneous removal through adsorption. Nevertheless, this approach necessitates a substantial adsorption capacity, leading to the need for a considerable quantity of adsorbent. Throughout recent years, a multitude of studies have been published regarding the specific adsorption of colourants. Nevertheless, despite the numerous favourable reviews on dye adsorption, there is a lack of literature that specifically addresses the topic of selective dye adsorption (Shi et al., 2022). A study conducted by Putri (2024) focused on the selective adsorption of anionic dyes using Macroalgae *E. Cottonii*. Similarly, Wang et al. (2024) investigated the selective adsorption of mixed dyes, such as Methyl Orange (MO) with Methylene Blue (MB), and Methyl Orange (MO) with Rhodamine-B (RhB), using a magnetic chitosan-lignin composite.

In this study, the selectivity of anionic dye substances was investigated using Graphene Oxide (GO) material. The focus was on the material's ability to absorb the highest amount of dye pollutants among the three types of dye mixtures. The mixture consisted of Direct Yellow (DY), Methyl Orange (MO), and Congo red (CR) dyes, which were subjected to a 10-minute process.

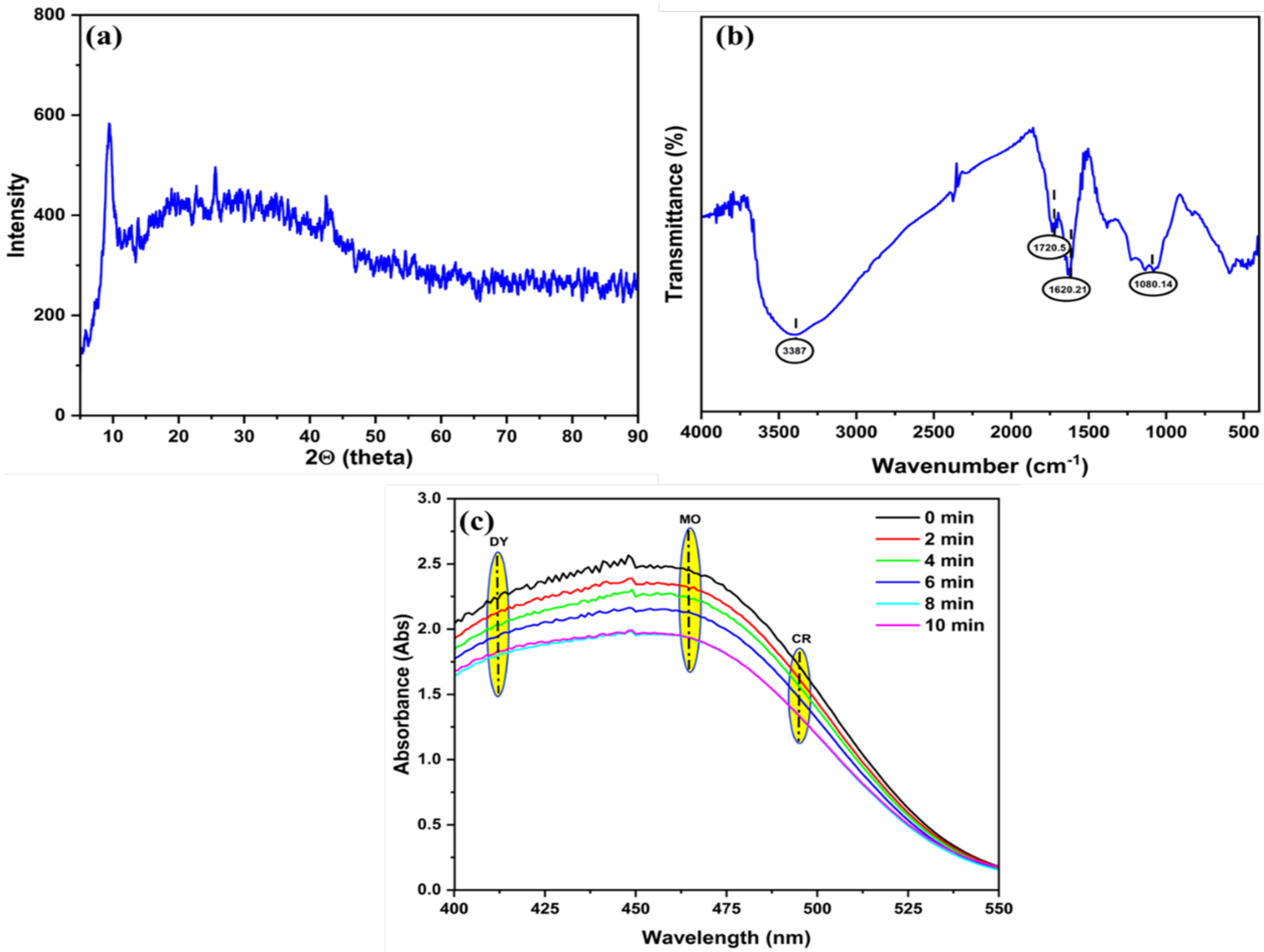

Figure 1. Characterization of Graphene Oxide with Regard to a) XRD, b) FT-IR, c) Selectivity of Anionic Dyes

2. EXPERIMENTAL SECTION

2.1 Materials and Methods

This study utilized various chemical substances including graphite, sulfuric acid (H_2SO_4), sodium nitrate ($NaNO_3$), hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), distilled water (H_2O), direct yellow (DY), methyl orange (MO), and congo red (CR). The material was characterized using a Rigaku Miniflex-600 X-ray diffractometer and a Shimadzu Prestige-21 FTIR spectrophotometer. The measurement of dye selectivity was conducted using a UV-Visible spectrophotometer, specifically the Biobase UV BK-1800PC.

2.2 Methods

2.2.1 Synthesis of Graphene Oxide

The synthesis process of Graphene Oxide is carried out using the Hummers method. A mixture of 3 grams of graphite and 1.5 grams of $NaNO_3$ was carefully combined in a glass beaker. Next, 69 mL of H_2SO_4 was carefully added and thoroughly mixed until the mixture achieved a consistent uniformity. 9 grams of $KMnO_4$ were carefully added at a temperature below 20°C. The mixture was stirred for a period of 7 hours at a temperature of 35°C. Another 9 grams of $KMnO_4$ was added to the mixture and stirred for a period of 14 hours. The resulting mixture was allowed to sit at room temperature and slowly added with 400 mL of distilled water and 3 mL of H_2O_2. In the following step, the mixture was filtered and washed with distilled water. The sample was dried in an oven at a temperature of 65°C for a period of 72 hours.

2.2.2 Selective Adsorption Analysis

In a chemical glass, a solution containing anionic dyes with concentrations of 50 mg/L each was carefully added. The dyes used were direct yellow, methyl orange, and congo red, with 10 mL of each dye being included. A combination of anionic dyes was mixed with 0.02 g of GO adsorbent and stirred for a duration of 10 minutes. Subsequently, the wavelength was determined

Table 1. Percentage Decrease in Absorbance Intensity on Anionic Dye Selectivity Using GO

Material	Dye	Percentage Decrease in Absorbance Intensity (%)
GO	DY	17.77
	MO	20.98
	CR	22.21

by employing a UV-Vis spectrophotometer at regular 2-minute intervals.

3. RESULTS AND DISCUSSION

The X-ray Diffraction Analysis of GO is shown in Figure 1(a). The obtained results indicate a diffraction peak at an angle of 2θ = 9.45° with the (001) plane and a spacing of approximately 9.35 Å, suggesting a high-quality GO material (Chethan et al., 2024; Dou et al., 2024). In addition, the obtained results demonstrate that the utilized graphene oxide effectively represents the surface characteristics of graphene oxide (Dou et al., 2024).

The FTIR spectrum of the GO can be observed in Figure 1(b). The strong peak at 3387 cm^{-1} is attributed to the stretching vibration of O−H, which indicates the presence of the −OH group in the structure (Li et al., 2024; Zhao et al., 2024). The stretching vibration of the carbonyl (C=O) bond was observed at 1720.5 cm^{-1} (Mahich et al., 2024; Palmieri et al., 2023). The strong peaks at 1080.14 cm^{-1} and 1620.21 cm^{-1}, respectively, are characteristic of aromatic C=C stretching and C−O−C stretching (epoxy group) (Hossain et al., 2024; Yang et al., 2024). Functional groups such as hydroxyl, carbonyl, and carboxyl groups are characteristic features found on the surface of graphene oxide.

Removing specific dyes selectively from wastewater holds significant importance in minimizing production costs (Lesbani et al., 2024). In order to comprehend the adsorption performance of GO on various types of dyes, anionic dyes such as DY, MO, and CR were selected for testing in the selectivity process. Based on Figure 1(c), it can be observed that there is a decrease in the peak intensity of the dye over time for DY (412 nm), MO (464 nm), and CR (495 nm). The obtained results indicate that GO material exhibits preferential adsorption for the anionic dye CR, with a significant decrease in peak intensity, followed by the dye MO, and finally the dye DY.

Based on the data in Table 1, it can be observed that the highest percentage decrease in absorbance intensity is exhibited by the CR dye, with a percentage value of 22.21%. Meanwhile, the colorants MO and DY have respective percentage values of 20.98% and 17.77%. This finding demonstrates that GO material exhibits a high level of selectivity in its ability to absorb CR dye among other cationic dyes.

4. CONCLUSIONS

In this paper, graphene oxide material was successfully synthesised using the Hummers method. The performance of graphene oxide material demonstrates selective adsorption towards the anionic dye congo red compared to the anionic dyes methyl orange and direct yellow, with the former being the second and the latter being the last in terms of adsorption efficiency.

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