Using Activated Carbon and Graphene to Treat Synthetic Textile Wastewater Containing Basic Blue 3 Dye

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Abstract

Basic Blue 3 (BB3), one of the dyes frequently used in the textile industry, is a toxic material that imparts a blue colour to aqueous environments when discharged into the natural environment without undergoing oxidation. Consequently, its discharge into the ecosystem without disposal reduces the oxygen level necessary for life by reducing light transmittance in the aqueous environment due to its color. Therefore, it negatively affects the ecosystem. In this thesis, based on this problem, the removal of toxic Basic Blue 3 (BB3) dyestuff from aqueous media was carried out by adsorption method using activated carbon and graphene adsorbents. The adsorption method was preferred due to its advantages.

These advantages include low cost, rapid processing, and high removal rates. In the adsorption experiments, the optimum adsorbent dose, the starting amount of dye, the length of time they are in contact, the temperature, and the stirring speed were calculated for both adsorbents. For activated carbon; 20 mg/L, 0,05g, 60 min, 40 ºC, 150 rpm, for graphene; 30 mg/L, 0,03g, 60 min, 25 ºC, 180 rpm.

Keywords: Adsorption, activated carbon, basic blue 3, graphene, wastewater.

1. Introduction

Environmental problems are undoubtedly one of the most significant problems in today's world, but among the greatest environmental challenges is the lack of clean water resources and the difficulty of accessing safe drinking water [1,2]. Water, one of the most abundant substances on our planet, covers approximately 75% of the Earth's surface. However, approximately 97% of this water is found in oceans and other saltwater bodies, making it unfit for human consumption. Most of the remaining 3%, approximately 2%, is seen as soil moisture, polar ice caps, and water vapor in the atmosphere. Although not evenly distributed across the Earth, the amount of water available for domestic, industrial, and agricultural use from groundwater, rivers, and lakes constitutes 0.62% of the total water on Earth [3]. Large amounts of solid, liquid, and gaseous waste are released into the environment as a result of industrial production, agricultural activities, and urbanization. A significant portion of these wastes constitute hazardous wastes that pose a threat to life. Hazardous wastes are common pollutants in wastewater, many of which are carcinogenic and/or toxic [4]. The reconsideration of environmental pollution at the end of the last century has shown that waste from the chemical industry has become a serious global threat to human health and the environment [5].

The increasing amount of organic compounds in natural waters has occurred as a result of the advancement of chemical technologies, mainly focused on organic synthesis and processing. Population growth and urban expansion have increased the pressure on water resources, especially in regions where these resources are limited, making it inevitable to develop low-cost and effective technologies for wastewater treatment [6]. Textile industry waste, particularly those containing high levels of dye chemicals, constitutes a primary source of water pollution. Furthermore, organic dyes are widely used in industrial processes. For this reason, it is of great importance to reduce the dye concentrations of wastewater before it is discharged into the environment. Uncontrolled discharge of textile wastewater containing dyes, organic matter, bleach, and salt into natural water resources significantly impacts the chemical and physical properties of freshwater. The dyes found in wastewater significantly reduce light transmittance and are highly resistant to heat and light, indicating that they are highly toxic to microorganisms [7].

2. Materials and Methodology

2.1 Equipment and Chemicals

All chemical reagents used during the experiments were of analytical purity and were used directly without any additional purification processes. Basic Blue 3 (BB3) dye provided by Sigma Aldrich was used as received. A 1000 mg/L stock solution of BB3 dye ($C_{20}H_{26}ClN_3O$; molecular weight = 359.89 g/mol; λ max = 654 nm) was made using deionized water. Experimental solutions were prepared by diluting appropriate amounts of this stock solution.

2.2 Instrumentation

During the experimental research, the following instruments were used: an analytical balance (Radwag), deionized water supplied by a purification device (Mikrotest MSD 08), a UV-Vis spectrophotometer (Agilent 8453), and an agitated water bath (Julabo SW22).

2.3 Batch Mode Adsorption

To examine the adsorption of BB3, 50 mL of BB3 solution at the desired concentration was taken from the prepared stock solutions and transferred to a 100 mL glass beaker.

Throughout the experiments, batch adsorption was conducted at room temperature (25 °C) under laboratory conditions on a water bath shaker with varying amounts of adsorbent for a specific time. The effects of various parameters, including adsorbent amount (0.005-0.1 g), initial dye concentration (5-50 mg/L), contact time (5-180 minutes), temperature (25-50 °C), and shaking speed (100-180 rpm were investigated. The absorbance value at the maximum wavelength (654 nm) was analyzed and recorded using a UV-Visible spectrophotometer. Equation 1 was used to calculate the percent removal (%R) of BB3 dye in the solution:

$$\%R = \frac{(C_o - C_e)}{C_o} x\, 100 \tag{1}$$

C_o in Equation 1 represents the initial dye concentration, and C_e represents the dye concentration measured at equilibrium (mg/L).

3. Results and Discussion

3.1 Adsorbent Dosage Effect on BB3 Removal

To examine the effects of changes in the amount of adsorbent on the % removal values, different amounts of adsorbent were weighed, and the experiments were repeated in a particular range (0.005 g - 0.1 g). 50 mL of 30 mg/L BB3 solution was added to each beaker. These prepared solutions were stirred at 25 °C at 150 rpm for 30 min using a shaker water bath. Then, the solution part was separated, and the sample was measured using a UV–Vis spectrophotometer operating at λ_{max} 654 nm.

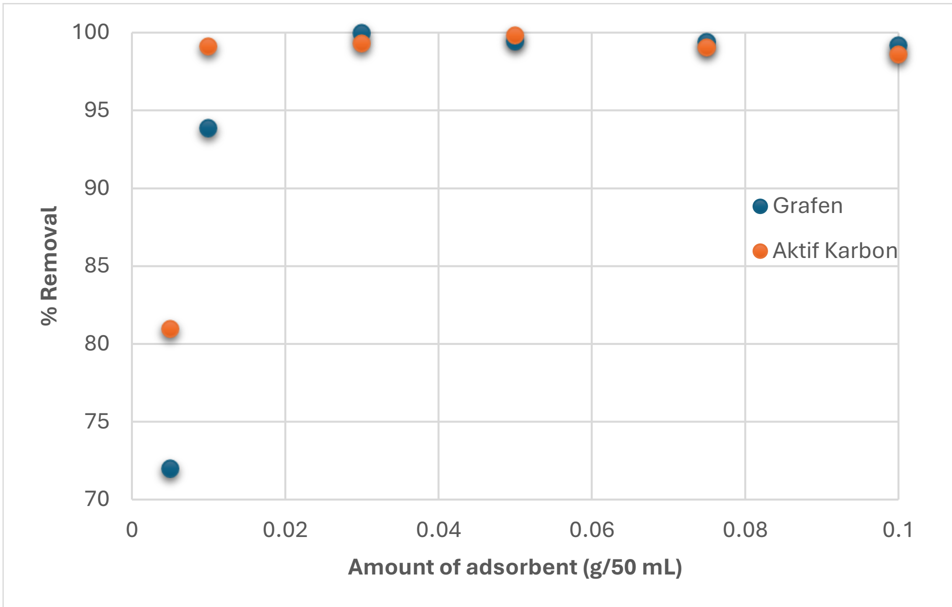

Figure 1. Effect of adsorbent dosage on activated carbon and graphene-based removal performance

Figure 1 illustrates the data on removal efficiency. Accordingly, the percentage removal (%R) values for BB3 dye at a concentration of 30 mg/L are 0.05 g for activated carbon and 0.03 g for graphene, respectively.

3.2 Impact of Starting Dye Quantity on BB3 Adsorption

In order to investigate the effect of beginning dye concentration on the adsorption of BB3 dye, experiments were carried out at different concentration ranges (5-50 mg/L). In this experiment, the optimum adsorbent amount for BB3 dye (0.05 g for activated carbon and 0.03 g for graphene) was weighed, placed in 100 ml glass beakers, and 50 ml of BB3 dye at different concentrations were added. These prepared solutions were stirred in the laboratory using a shaking water bath at 150 rpm for 30 minutes at 25 °C. Percent removal values were calculated by measuring the absorbance of a sample taken from the solution.

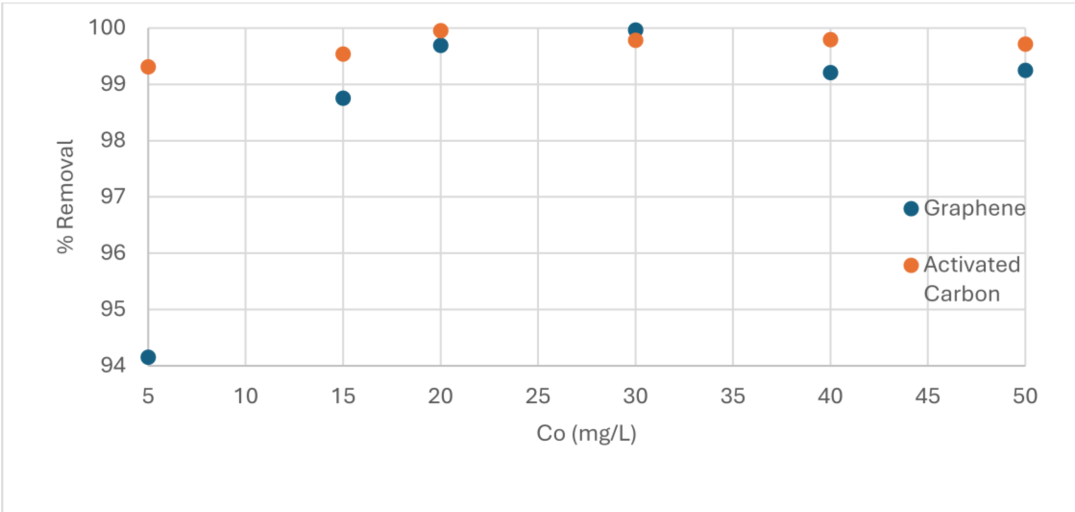

Figure 2. Influence of initial dye concentration on activated carbon and graphene removal efficiency.

When the data in Figure 2 is examined, the adsorption removal percentage for activated carbon reached 99.95% at the optimum concentration of 20 mg/L of BB3 dye. The solution at a concentration of 5 mg/L of BB3 dye was not saturated with the dye and therefore did not reach optimum conditions. As the concentration of BB3 dye was increased during the adsorption process with activated carbon, the removal percentage increased until reaching the optimum value and then decreased by a small margin.

When Figure 2 is examined for graphene, it is understood that the adsorption removal percentage reached 99.96% at the optimum concentration of 30 mg/L of BB3 dye. At a concentration of 5 mg/L of BB3 dye, the solution was not saturated with the dye and did not reach optimum conditions. As the concentration of BB3 dye was increased during the graphene adsorption process, the removal percentage increased until reaching the optimum value and then decreased.

3.3 Impact of Contact Time

To study the effect of interaction time on BB3 dye removal, 50 mL of each 20 mg/L BB3 for activated carbon and 30 mg/L BB3 for graphene were placed in 100 mL glass beakers. The optimum weight of each adsorbent, 0.05 g of activated carbon and 0.03 g of graphene, was weighed and added. The solution mixture was shaken at 25 °C, 150 rpm, for 5 to 180 minutes.

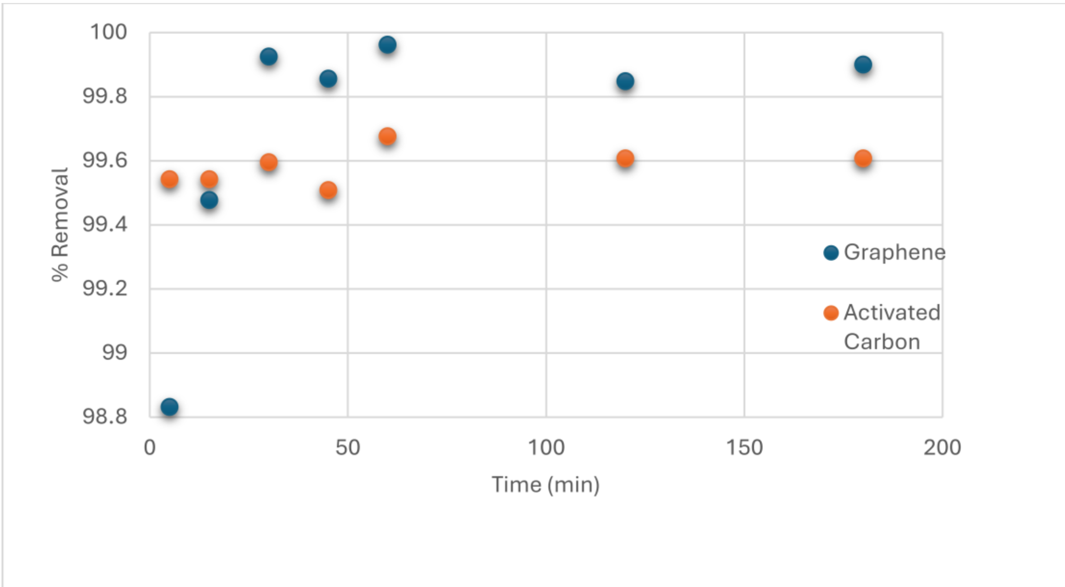

Figure 3. Impact of contact time on activated carbon and graphene removal efficiency.

As illustrated in Figure 3, the BB3 dye adsorbed by activated carbon within 60 minutes achieved the highest removal rate of 99.67%. The BB3 dye adsorbed by graphene within 60 minutes achieved the highest removal rate of 99.96%. This shows that the adsorbent's vacant sites became occupied by the adsorbate (dye), reaching equilibrium.

3.4 Impact of Temperature

To investigate the effect of temperature on the BB3 dye solution, experiments were carried out under the following conditions: 50 ml of the optimum concentration of each dye solution (20 mg/L BB3 for the activated carbon solution and 30 mg/L BB3 for the graphene solution), stirring speed of 150 rpm for the activated carbon and 150 rpm for the graphene, contact time for each solution (60 min for the activated carbon and 60 min for the graphene) and adsorbent dosage of 0.05 g of activated carbon and 0.03 g of graphene at different temperatures ranging from 25 to 50 °C.

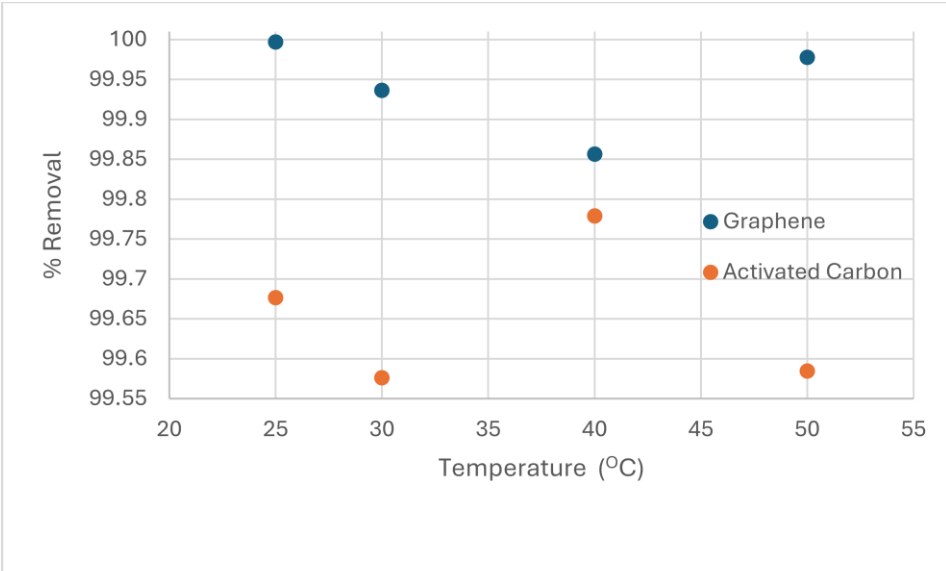

Figure 4. Influence of temperature on the adsorption performance of activated carbon and graphene adsorbents.

Figure 4 presents the optimum removal efficiency values. It shows that the highest percentage removal (%R) for the activated carbon and graphene adsorbents was observed at 40 °C (activated carbon) and 25 °C (graphene), respectively. At equilibrium, the percentage removal of BB3 dye increased from 99.67% to 99.77% as the temperature increased from 25 °C to 40 °C for the activated carbon adsorbent. At equilibrium, the percentage removal of dye for the graphene adsorbent increased from 99.85% to 99.99% as the temperature increased from 40 to 50°C.

3.5 Effect of Shaking Speed

The effects of shaking speed on activated carbon and graphene and BB3 dye can be eliminated. For activated carbon, 50 ml of BB3 at 20 mg/L was purchased and a 100 ml glass was obtained. A 0.05 g portion of activated carbon was taken and transferred into the solution. The solution was stirred at 40 °C with a dispersion speed of 100-180 rpm for 60 minutes. In the same process, for the graphene adsorbent, 0.03 g of graphene was weighed in a 30 mg/L BB3 solution and shaken at 25 °C with permanent speeds between 100 and 180 rpm for 60 minutes.

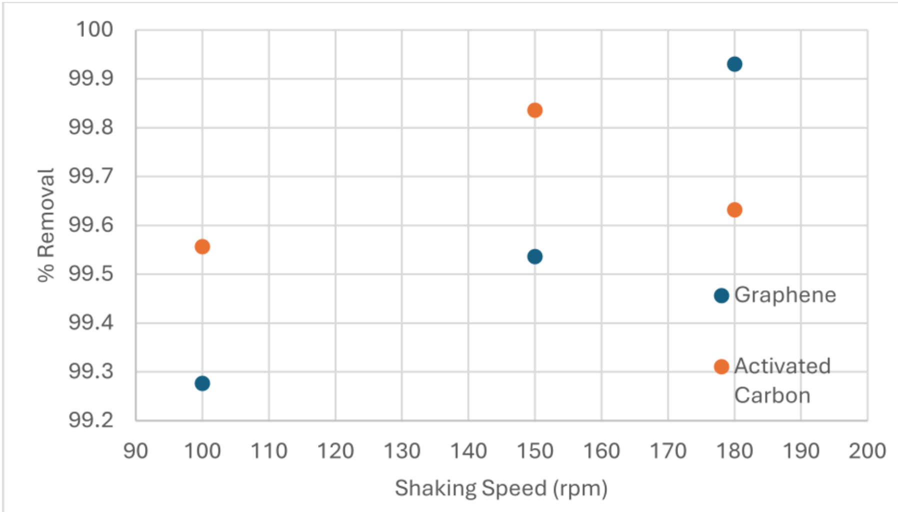

Figure 5. Effect of stirring speed on the removal efficiency of activated carbon and graphene adsorbents.

When the data in Figure 5 is examined, it is observed that the percentage removal (%R) of the saturated carbon and graphene adsorbents reached optimal levels at 150 rpm and 180 rpm stirring speeds, respectively.

In experiments conducted with increasing agitation speeds, the removal rate of BB3 dye on the activated carbon adsorbent increased from 99.55% to 99.83%. The removal rate of BB3 dye on the graphene adsorbent increased from 99.27% to 99.93% with increasing agitation speeds. Increasing agitation speed can increase the outer film diffusion and adsorption rate by reducing the film boundary layer surrounding the adsorbent particles. However, increasing agitation speed increased the adsorption rate of BB3 dye on the activated carbon adsorbent in the 100-150 rpm range and decreased it in the 150-180 rpm range. This result suggests that the effect of agitation speed varies depending on the type of adsorbent.

Conclusion

Based on the experimental results, adsorption experiments using activated carbon and graphene as adsorbents demonstrated that both adsorbents were successful in removing the BB3 synthetic dye solution. The removal efficiency of the dye reached over 99% under optimal conditions. Based on the experiments, the optimum values for various parameters were obtained as follows:

The amount of BB3 used for cleaning Basic Blue 3 with activated carbon was: 50 mL at a concentration of 20 mg/L, using 0.05 g of activated carbon adsorbent, for 60 minutes at 150 rpm and 40 °C. Similarly, the amount of BB3 used for cleaning Basic Blue 3 with graphene was found to be 50 mL at a concentration of 30 mg/L, using 0.03 g of graphene adsorbent, for 60 minutes at 180 rpm and 25 °C.

This study is expected to advance wastewater treatment by using effective adsorbents in adsorption, a safe, affordable, simple, and efficient low-cost method for removing hazardous compounds such as synthetic dyes and heavy metals released from various industries and human activities.

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