

Comparative Study of Magnesium Oxide and Activated Charcoal for Organic Dye Removal from Aqueous Solutions

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Abstract—The adsorption properties of Magnesium Oxide (MgO), activated charcoal, and a composite mixture of these substances in a 1:1 ratio are examined for the present study. A batch experimental approach was used, guaranteeing the accuracy of the findings by preparing and testing the sample in triplicate. Reactive Orange (RO16) and Amaranth dyes adsorb onto the adsorbents were thoroughly examined by considering the impact of several experimental factors, such as pH levels, contact time, and adsorbent dosage. According to the results, adsorption capacity was highest at a 1:1 composite ratio of adsorbents. RO 16 demonstrated the highest adsorption capacity (8.62 mg/g) at pH 7 and a contact period of 5 minutes. The maximum amaranth capacity (9.55 mg/g) was seen at pH 7 and after 15 minutes of contact time. Additionally, improved regeneration trials over five cycles demonstrated that MgO was more reusable than activated charcoal, which lost 3.63 mg/g of adsorption capacity, with a loss of just 0.54 mg/g.

Keywords—Activated charcoal, Adsorption, Amaranth dye, Dye removal, Reactive orange 16.

I. INTRODUCTION

Water is an essential component for all living organisms. It is the primary medium for cell biochemical reactions, aiding nutrient transport, waste removal, and temperature regulation. It serves as an essential environment for aquatic plants and animals and offers homes to many species [1]. Wastewater, an inevitable byproduct of human activities, is a term that encompasses used or contaminated water originating from various sources. As societies continue to develop and expand, the generation of wastewater has become a significant concern due to its potential to harm the environment and human health. Wastewater can have a wide range of compositions depending on its origin. It could include infections, chemicals, heavy metals, oils, nutrients, and other pollutants in addition to organic and inorganic materials. Due to their ability to provide vibrant colors, organic dyes are widely used in various industries, such as textiles, plastics, and packaging materials. However, the health impacts of organic dye have raised concerns, leading to a growing interest in eco-friendly alternatives and remediation strategies. The environmental impact of organic dyes is a significant concern, as they are known to pollute industrial effluents and have detrimental effects on ecosystems. Additionally, experts have highlighted the health and environmental impacts of dyes, emphasizing the need for effective remediation strategies. MgO stands out as a premier adsorbent material within industrial wastewater treatment, particularly adept at addressing the presence of heavy metals and dyes in aqueous solutions [1]. In addition to magnesium oxide, activated charcoal is another pivotal material in wastewater treatment. Various forms, including coconut shell charcoal and commercially modified activated carbon, exhibit enhanced capabilities in removing Cr (VI) from synthetic

wastewater compared to their untreated counterparts [3]. This research addresses the challenge of organic dye removal, specifically Reactive Orange 16 and Amaranth from aqueous solutions. By leveraging the unique properties of MgO and activated charcoal, the aim is to devise an effective and sustainable solution for the remediation of water contaminated with organic dyes. Adsorption is a widely used technique for treating dye-containing water because it is inexpensive, highly effective, and straightforward [3]. This research aims to optimize the adsorbent materials in the color-removal process inexpensively. Change in batch experimental testing to evaluate the best condition for adsorption of Reactive orange (RO 16) from aqueous solutions. Moreover, reusability was also tested for materials.

II. MATERIALS AND METHODOLOGY

This section provides an overview of the materials utilized in the experiment and explains the scientific methodologies employed in the study.

Materials

All the agents as mentioned earlier, and chemical materials were used without any modifications. All solutions are prepared with distilled water. The MgO powder in Fig. 1 (a) is used as it is in the laboratory.

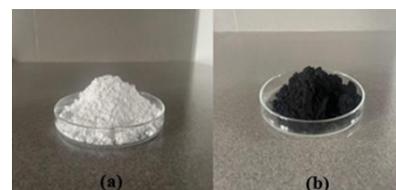


Fig. 1. Photograph of (a) MgO and (b) activated charcoal

Activated charcoal powder Fig. 1 (b) is used as it is. Reactive Orange 16 (RO16) is a model reactive dye, and Amaranth is an acidic dye [4] Both have different chemical structures (Fig. 2,3), and the chemical structure determines the nature of each dye; RO16 has two sulfonate groups, which have negative charges in an aqueous solution [5].

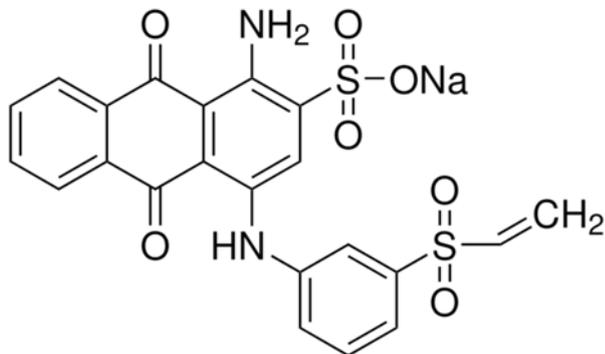


Fig. 1. Chemical structure of Reactive Orange 16

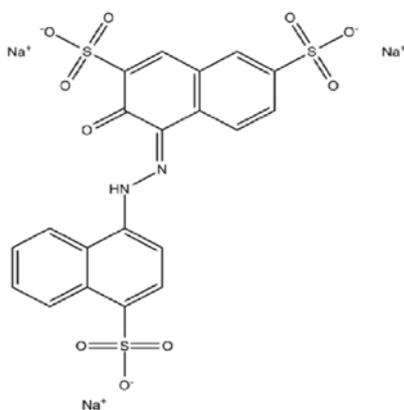


Fig. 2. Chemical Structure of the Amaranth.

The physical and chemical properties of the two adsorbents are shown in Tables 1 and 2.

TABLE 1. Physical properties of the magnesium oxide

| Physical properties | |
|---|------------|
| color | White |
| Shape | Amorphous |
| Purity | 99.64% |
| Solubility in dilute acid | 97-100% |
| Filling Volume(min) | 100ml/15gm |
| Loss on ignition (at 900 C) | 9% |
| Substances insoluble in acetic acid | 0.1% |
| Substances insoluble in hydrochloric acid | 0.1% |

TABLE 2. Physical and Chemical properties of the Activated charcoal.

| Chemical properties | | Physical properties | |
|--------------------------|---------|------------------------|-----------|
| Grade | K15060 | Particle size(mm) | 2.00-3.35 |
| pH | 9-11 | Bulk density(t/m3) | 0.61 |
| Ash content | 5% max. | Particle density(t/m3) | 1.18 |
| Iodine number (mg/g.min) | 1000 | Void ratio (%) | 47 |
| SiO ₂ | 2.9% | | |

The general characteristics of RO16 are summarized in Table 3.

TABLE 3. General Characteristics of Reactive Orange 16

| Characteristics | Description |
|--------------------------------|---|
| Chemical formula | C ₂₀ H ₁₇ N ₃ Na ₃ O ₁₁ S ₃ |
| Molar mass | 617.54 |
| Maximum wavelength, λ max (nm) | 494 |
| Appearance | Bright yellow orange |
| Melting point | >300 °C |

TABLE 4. General Characteristics of Amaranth

| Characteristics | Description |
|--------------------------------|---|
| Chemical formula | C ₂₀ H ₁₁ N ₃ Na ₃ O ₁₀ S ₃ |
| Molar mass | 604.47 |
| Maximum wavelength, λ max (nm) | 520 |
| Appearance | Dark red solid |
| Melting point | 120 °C |

Methodology

Triplicate sample Batch removal studies carried out the adsorption of dyes on MgO and Activated charcoal [1] The stock solution of 20mg/L (20 ppm) was prepared by dissolution of dyes into distilled water. A given mass of MgO and Activated charcoal materials was added to the aqueous solutions of dyes. The solid phase separated from the suspension after shaking the given time at 100RPM. An ultraviolet spectrophotometer was used to determine the dye solution's concentration after filtering. The adsorption capacity (Q_e) and removal efficiency(R) were calculated as Eq. (1) and Eq. (2) [1]

$$\text{Adsorption capacity } (Q_e) = \frac{(c_0 - c_t)v}{M} \quad \text{Eq. 01}$$

$$\text{Removal efficiency } (R) = \frac{(c_0 - c_t) \times 100\%}{c_0} \quad \text{Eq. 02}$$

Where Q_e is the adsorption of the dye(mg/g), C₀ is the initial concentration of dye (mg/ml), C_e is the equilibrium concentration of dye (mg/ml), M is the weight of the adsorbents used (g), and V is the volume of dye solutions(L).

Experimental conditions such as contact time, adsorbent dosage, pH, and initial dye concentration were optimized to evaluate the adsorption capacity [2] The pH of the solution was adjusted with 0.1 mol/L NaOH or 0.1 mol/L HCl.

Reusability experiments

After adsorption, MgO and activated charcoal were thoroughly cleaned by ultrasonication in ethanol and centrifugation and subsequently activated by drying in an oven at 353 K for 12 h. Then, adsorbents were reused for the adsorption of dye solutions [2].

III. RESULTS AND DISCUSSION

This section presents the experimental findings derived from the experiments.

Effect of Adsorbent dosage.

The impact of adsorbent dosage on dye removal was analyzed individually for each dye. Table 5 illustrates how varying adsorbent dosages affect the removal of Reactive Orange 16 using magnesium oxide, activated charcoal, and a combination of both. Increasing the dosage of MgO led to higher removal efficiency, attributed to increased particle collision between color and adsorbent particles. However, the adsorption capacity decreased as the number of color particles remained constant. Similarly, activated charcoal demonstrated

improved removal efficiency with dosage increment, yet, like magnesium oxide, experienced a decrease in adsorption capacity due to constant color particle concentration. Conversely, the mixed adsorbents decreased removal efficiency with dosage increment, as the interaction between MgO and activated charcoal reduced the chances of adsorbent-particle collision.

TABLE 5. Adsorption capacity and removal efficiency change with a adsorbent dosage variations for Reactive Orange 16.

| Dosage (mg) | Magnesium oxide | | Activated Charcoal | | Mixing Adsorbent | |
|-------------|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| | 100 | 6.57 | 65.72 | 4.91 | 49.15 | 8.62 |
| 150 | 4.45 | 66.82 | 5.05 | 75.73 | 5.65 | 84.73 |
| 200 | 3.65 | 73.00 | 3.89 | 77.84 | 4.19 | 83.82 |

Table 6 presents experimental results for amaranth dye removal, where all three cases outperformed Reactive Orange 16. The maximum adsorption capacity was achieved with a 100mg dosage, resulting in a 92.23% removal efficiency for mixed adsorbents. Dosage increments for amaranth dye removal enhanced the overall performance across all three cases compared to Reactive Orange 16.

TABLE 6. Adsorption capacity and removal efficiency change with a adsorbent dosage variations for Amaranth

| Dosage (mg) | Magnesium oxide | | Activated Charcoal | | Mixing Adsorbent | |
|-------------|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| 100 | 8.59 | 85.93 | 9.01 | 90.09 | 9.22 | 92.23 |
| 150 | 5.88 | 88.15 | 6.13 | 92.02 | 6.32 | 94.78 |
| 200 | 4.53 | 90.57 | 4.73 | 94.57 | 4.76 | 95.27 |

Effect of Contact time.

The impact of contact time on adsorption was examined individually for each dye. Table 7 demonstrates the adsorption of Reactive Orange 16 using magnesium oxide, activated charcoal, and a combination of both. Increasing the contact time in experiments with MgO and activated charcoal resulted in higher adsorption capacity and removal efficiency. This improvement occurred because a longer contact time allowed for an extended period of adsorption by the adsorbents. However, experiments involving mixed adsorbents showed a slight decrease in both adsorption capacity and removal efficiency with increased contact time. This decline can be attributed to the prolonged mixing time, which led to the desorption of adsorbents and color particles, thereby reducing their effectiveness in the adsorption process.

TABLE 7. Adsorption capacity and removal efficiency change with Contact time variations with 100mg of adsorbents for Reactive Orange 16.

| time (Min) | Magnesium oxide | | Activated Charcoal | | Mixing Adsorbent | |
|------------|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| 5 | 6.51 | 65.12 | 6.64 | 66.43 | 8.61 | 86.10 |
| 10 | 7.33 | 73.30 | 6.98 | 69.77 | 8.44 | 84.38 |
| 15 | 7.92 | 79.23 | 7.55 | 75.49 | 8.45 | 84.37 |

Table 8 displays the experimental process for the removal of amaranth dye using three different adsorbents under varying

contact times. As the contact time increases, both the adsorption capacity and removal efficiency show improvement across all experiments. The highest removal efficiency of 95.51% was achieved with a contact time of 15 minutes when using mixed adsorbents.

TABLE 8. Adsorption capacity and removal efficiency changing with Contact time variations with 100mg adsorbents for Amaranth.

| time (Min) | Magnesium oxide | | Activated Charcoal | | Mixing Adsorbent | |
|------------|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| 5 | 8.63 | 86.27 | 8.92 | 89.21 | 9.30 | 92.97 |
| 10 | 9.12 | 91.17 | 9.03 | 90.34 | 9.49 | 94.89 |
| 15 | 9.43 | 94.27 | 9.16 | 91.57 | 9.55 | 95.51 |

Effect of pH level.

The impact of pH levels was examined individually for each dye. Throughout the adsorption process, the pH of the solution emerged as a crucial factor, exerting influence on the charge of the adsorbent. This, in turn, affected the dissociation of functional groups present on the binding sites of the adsorbent. The experimental findings regarding adsorption under varying pH conditions are detailed in Tables 9 and 10. Lower pH levels (acidic) demonstrated heightened adsorption capacity for both dyes. As the pH increased from 3 to 11, there was a consistent decline in adsorption capacity and removal efficiency. Reactive dyes, such as RO16, comprise functional groups capable of ionization in aqueous solutions. Under acidic conditions, these dyes predominantly exist in their protonated forms, fostering a stronger affinity for adsorption onto adsorbent surfaces owing to electrostatic interactions. With an elevation in pH (transitioning towards alkalinity), the functional groups on the dye molecules begin to deprotonate. This ionization process reduces the overall positive charge on the dye molecules, consequently diminishing the electrostatic attraction between the dye molecules and the negatively charged adsorbent surface.

Consequently, the adsorption capacity of the adsorbent for RO16 dye molecules also declines, leading to fewer dye molecules being adsorbed onto the adsorbent surface at higher pH levels than lower ones. Like Reactive Orange 16, Amaranth Dye contains functional groups capable of ionizing in aqueous solutions. Under acidic conditions, these dyes primarily exist in their protonated forms, typically exhibiting greater affinity for adsorption onto surfaces due to electrostatic interactions. However, as the pH level increases, the deprotonation of functional groups on the amaranth dye molecules occurs, reducing their positive charge and consequent electrostatic attraction with the adsorbent surface. As observed with RO16, the adsorption capacity of the adsorbent for amaranth dye molecules diminishes at higher pH levels, resulting in fewer dye molecules being adsorbed onto the adsorbent surface compared to lower pH levels. Additionally, at higher pH levels, concurrent competing reactions such as hydrolysis or complexation reactions may further diminish the efficiency of the adsorption process.

TABLE 9. Adsorption capacity and removal efficiency change with pH level variations with 100mg of adsorbents for Reactive Orange 16

| pH | Magnesium oxide | | Activated Charcoal | | Mix | |
|----|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| 3 | 8.44 | 84.42 | 8.37 | 83.71 | 8.74 | 87.43 |
| 7 | 6.81 | 68.10 | 7.23 | 72.26 | 7.52 | 75.15 |
| 11 | 6.20 | 61.99 | 5.63 | 56.34 | 6.79 | 67.87 |

TABLE 10. Adsorption capacity and removal efficiency change with pH level variations with 100mg of adsorbents for Amaranth.

| pH | Magnesium oxide | | Activated Charcoal | | Mix | |
|----|-----------------------|-------|-----------------------|-------|-----------------------|-------|
| | Q _e (mg/g) | R % | Q _e (mg/g) | R % | Q _e (mg/g) | R % |
| 3 | 9.02 | 90.22 | 9.94 | 94.41 | 9.33 | 93.30 |
| 7 | 7.74 | 74.44 | 8.91 | 89.13 | 8.37 | 83.69 |
| 11 | 6.67 | 66.67 | 7.54 | 75.36 | 7.20 | 72.04 |

Reusability of adsorbents.

Fig. 4 illustrates the changes in adsorption capacity for MgO and activated charcoal over five repeated cycles. In the first cycle, MgO exhibited an adsorption capacity of 3.76 mg/g, decreasing slightly to 3.22 mg/g by the end of the five cycles. This indicates a relatively high reusable capacity for magnesium oxide, with a decrease of only 0.54 mg/g in adsorption capacity over the cycles.

On the other hand, activated charcoal initially demonstrated an adsorption capacity of 3.73 mg/g, but this decreased substantially to 0.10 mg/g by the end of the five cycles. In comparison to magnesium oxide, activated charcoal displayed significantly lower reusable capacity, experiencing a decrease of 3.63 mg/g in adsorption capacity over the cycles.

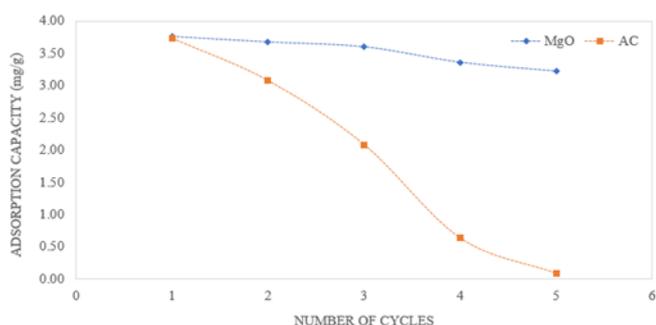


Fig. 3. MgO and activated charcoal adsorbent removal efficiency change with batch experimental cycles.

IV. CONCLUSION

In conclusion, the combination of MgO and activated charcoal demonstrates significant efficacy in the removal of

dyes from wastewater. Present experiments reveal that both amaranth and reactive orange dyes exhibit notable removal efficiency when treated with these adsorbents, particularly in a 1:1 ratio combination. Moreover, findings highlight the superior reusability of MgO compared to activated charcoal. These results suggest promising prospects for utilizing these adsorbent materials as cost-effective and environmentally benign solutions for industrial wastewater treatment. However, it is essential to acknowledge that our experimental procedures were conducted solely with synthetic dye samples at the laboratory scale. Further validation using actual industrial effluents is imperative before considering widespread industrial applications. Future research endeavors in this area hold significant potential for industries such as garment and food production, offering them viable means to address their dye effluent challenges. The notable removal efficiency observed in our study, coupled with the straightforward operational procedures, underscores the feasibility of integrating these adsorbents into existing wastewater treatment plants. Continued research efforts aimed at optimizing the adsorption capacity and removal efficiency of these adsorbents in wastewater treatment applications are warranted. By doing so, we can further enhance the effectiveness of dye removal processes, ultimately contributing to more sustainable industrial practices and environmental stewardship.

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