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Affordable Colorant Removal Using Activated Carbon of Potato Leaves: A Sustainable Alternative

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ABSTRACT

The current study shows that using a batch approach to remove colourant (DSDCBS) from water is feasible when using activated carbon obtained from potato leaves as an adsorbent. In order to investigate the effects of parameters, including starting concentration, pH effect, adsorbent dosage, contact time, and temperature, experiments were carried out under various operating conditions. The influence of pH and colourant concentration was shown to be substantial. Langmuir and Freundlich isotherm models were fitted to equilibrium data. The outcomes highlight the applicability of the affordable, locally accessible adsorbent in the speciality area of wastewater treatment and can be used in commercial colourant-enriched effluent.

1. INTRODUCTION

Activated carbon derived from agricultural waste holds significant importance in the field of environmental remediation, particularly for the removal of colourants from industrial effluents. As the demand for textiles, colourants, and various chemical processes continues to grow, so does the generation of wastewater containing harmful and often persistent colourant pollutants. Traditional methods of treating such effluents may prove insufficient, leading to the exploration of alternative, sustainable materials for effective pollutant removal.

Agricultural waste, a byproduct of various farming activities, presents a promising avenue for the production of activated carbon due to its abundant and renewable nature. Utilizing agricultural waste materials, such as crop residues, husks, or leaves, not only addresses the challenge of waste management but also transforms these residues into a valuable resource with distinct adsorptive properties.

Activated carbon, when derived from agricultural waste, exhibits a porous structure and high surface area, providing an ideal substrate for adsorption. This unique characteristic enables it to effectively capture and remove diverse colourant molecules from wastewater through physical and chemical interactions [1-3]. The adsorption process on activated carbon involves the binding of colourant molecules onto the surface of the carbon, preventing their release into water bodies and mitigating the environmental impact.

The significance of employing activated carbon from agricultural waste for colourant removal lies not only in its efficacy but also in its sustainable and eco-friendly nature. By repurposing agricultural residues that would otherwise contribute to environmental burdens, this approach aligns with the principles of circular economy and green chemistry.

This discussion delves into the various aspects of utilizing activated carbon derived from agricultural waste for colourant removal, including the production methods, adsorption mechanisms, and the potential impact on wastewater treatment processes. Examining the transformative potential of this sustainable solution contributes to the ongoing discourse on

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environmentally conscious practices in industrial and wastewater management.

In essence, the exploration and implementation of activated carbon from agricultural waste for colourant removal underscore the potential of harnessing nature's resources for environmental benefit. Moving forward, continued research and advancements in this field will play a pivotal role in shaping a more sustainable and resilient future for water treatment processes, fostering a balance between industrial growth and environmental stewardship.

2. MATERIALS AND METHODS

2.1 Adsorbate

DSDCBS (Disodium 2,5-dichloro-4-{(4Z)-3-methyl-5-oxo-4-[2-(4-sulfonatophenyl) hydrazinylidene]-4,5-dihydro-1H-pyrazol-1-yl}benzene-1-sulfonate) (Molecular Formula: $C_{16}H_{10}Cl_2N_4\ Na_2O_7S_2$)(M.Wt. 551.28) is a colourant used in surfactant and textile industries. For the present study, it is used as an adsorbate. It's structural formula is shown in Fig. (1).

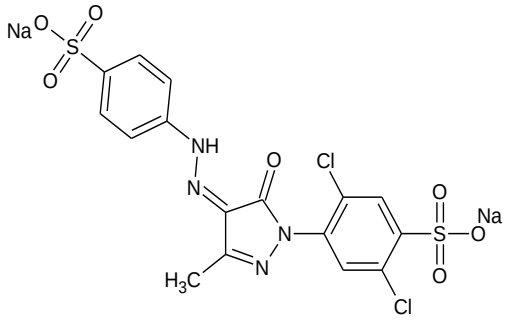

Fig.1. Structural formula of DSDCBS

2.2 Adsorbent

Potato leaves were collected from local fields and underwent a meticulous cleaning process, involving washing with water to eliminate impurities and undesirable materials. Subsequently, they were rinsed multiple times with distilled water and left to air-dry at room temperature for 8 days. Additional drying occurred in an oven at 100ºC for 24 hours. Following the drying process, the leaves were activated by impregnating them with phosphoric acid (65% by weight) at a 1:1 weight ratio (Leaves : acid). The impregnated leaves were subjected to a heating process at 200ºC for 60 minutes. After cooling, the sample underwent thorough washing using distilled water(40^0C) until the pH reached 7. Finally, the carbonized leaves were ground and passed through a 0.4 mm sieve plate to yield carbon of uniform size.[4-5]

2.3 Adsorption study

A 2-liter volumetric flask containing distilled water was filled with one gram of substance DSDCBS to form the stock solution(500 mg/L). Subsequently, the stock solution was stirred using a magnetic stirrer for 60 minutes to ensure a consistent distribution of the colorant.

Activated carbon obtained from potato leaves ranging from 0.1 to 0.8 grams were introduced into amber bottles containing 250 mL of a colorant solution with a concentration of 50 mg/L, adjusted to approximately pH 7. The mixtures underwent agitation at a rate of 180 rpm for 90 minutes at a temperature of 25°C, facilitated by a magnetic stirrer and filtration was done using Whatman filter paper (No. 1). The concentrations of the solutions were determined by UV-Vis spectrophotometer, and calibration curves were plotted for accurate estimation.

The adsorption evaluation was conducted at the optimal pH, employing different initial concentrations (25, 50, 100, and 150 mg/L) to explore equilibrium conditions. For each 250 ml colored solution at 25°C, 0.5 g of potato leaves were introduced and stirred using a magnetic stirrer for 4 hours. Samples were extracted at specific time intervals (in minutes): 0, 10, 20, 30, 45, 60, 90, and 120 for subsequent spectrophotometric analysis.

Once the concentration of the solution stabilized over time, indicating equilibrium was reached, the adsorption performance (expressed as percent colorant removal) and adsorption capacity (quantified as q, the amount adsorbed) were calculated using the following equations [6-7]:

$$\text{Adsorption capacity in}\frac{\text{mg}}{\text{g}} = \left(\frac{C_i - C_f}{M_{ads}}\right) \times V \quad (1)$$

$$\text{Removal efficiency in \%} = \left(\frac{C_i - C_f}{C_i}\right) \times 100 \quad (2)$$

where V = the solution volume (L), Mads = weight of adsorbent(g), C_i = initial concentration of the colourant solution(mg/L), C_f = final concentration of the colourant solution(mg/L).

2.4 Adsorption isotherm

The adsorption data were analyzed using Langmuir and Freundlich isotherm models. The Langmuir model describes the equilibrium distribution of the adsorbate (colorant) between solid and liquid phases. The linearized form of the Langmuir isotherm model is represented by the following equation [8-9]:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{K_L q_m} \quad (3)$$

where Ce is the equilibrium concentration of the adsorbate (colorant) in the liquid phase (mg/L), K_L is the Langmuir constant related to the energy of adsorption (L/mg), q_m is the maximum adsorption capacity of the adsorbent (mg/g), q_e is the equilibrium adsorption capacity of the adsorbent (mg/g).

The values of K_L and q_m were determined from the graph of C_e/q_e against C_e. Here, q_m was determined from the reciprocal value of the slope and K_L was determined by the value of the intercept. A dimensionless separation factor which is called R_L was determined by the consequent equation:

$$R_L = \frac{1}{1 + K_L C_i} \quad (4)$$

The isotherm model is considered favorable if R_L falls between 0 and 1, if $R_L = 1$, the isotherm model is considered linear, unfavorable, or irreversible if the value of $R_L > 1$ and $R_L = 0$, respectively [10].

An alternative approach, the Freundlich isotherm model, is employed to describe adsorption on heterogeneous surfaces and reversible adsorption processes [11-12]. The linearized form of

the Freundlich isotherm model is expressed by the following equation:

$$\ln(q_e) = \ln(K_F) + \frac{1}{nF}\ln(C_e) \quad (5)$$

where K_F represents the Freundlich isotherm constant measured in mg/g, $1/n_F$ is the heterogeneity factor associated with adsorption capacity. The natural logarithm of the equilibrium adsorption capacity (ln(qe)) was plotted against the natural logarithm of the equilibrium concentration (ln(Ce)) to determine the Freundlich adsorption isotherm constant (K_F) from the intercept value. The slope of the plot provided the value of nF, the Freundlich exponent. If 1/nF is less than 1, it indicates the favorable adsorption of the colorant. Conversely, if 1/nF is greater than 1, it suggests physical adsorption. When nF equals 1, the adsorption process is termed linear.

2.5 Desorption study

To initiate the desorption assessment, vacuum filtration was employed to separate the potato leaves (initially exposed to the colorant solution at 0.5 mg/L). The spent adsorbent underwent desorption processes, either individually or in combination, within acidic or basic mediums. Acidic and basic solutions were prepared using 0.1 M HCl or 0.1 M NaOH solutions, respectively. Before drying the sample for twenty-four hours at 80 °C, the adsorbent was rinsed thoroughly with distilled water five times to eliminate any residual acid or base solution.

3. RESULTS AND DISCUSSIONS

3.1 Effect of adsorbent amount

Fig. 2 demonstrates the relationship between the amount of adsorbent and the removal of colorant. With 1.6 gram of activated carbon from potato leaves, approximately 92% of the colorant was adsorbed, while 2.4 grams of adsorbent resulted in an 91% removal of the colorant.

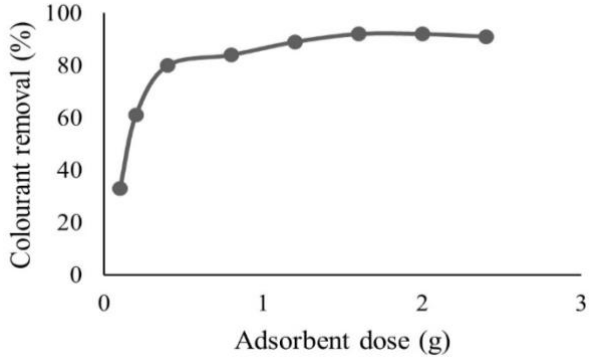

Fig. 2. Effect of adsorbent amount.
M_{ads}: 0.1 - 2.4 g, t: 60 min, C_i: 50 mg/L, T: 25 °C, pH = 6, volume of solution: 0.25L, S:180 rpm.

3.2 Effect of initial concentration and contact time

The impact of initial concentration (Ci) and contact time(minute) on the adsorption process was investigated using four concentrations of colorants: 25, 50, 100, and 150 mg/L. The graph illustrates the relationship between colorant removal and contact time, as depicted in Fig. 3, it shows that in the first 60 min, adsorption was very swift.

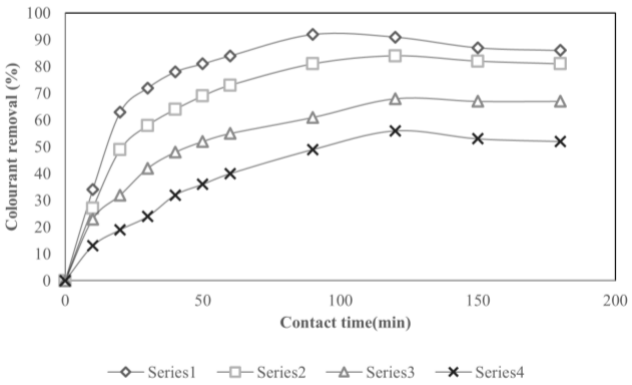

Fig. 3. Effect of initial concentration and contact time.
M_{ads}: 0.5 g, C_i: 25, 50, 100 and 150 mg/L (Series 1, 2,3,4 respectively), t: 0 - 180 min, pH: 7, T: 25 ^{0}C, volume of solution: 0.25 L, S: 180 rpm.

3.3 Effect of pH of solution

As depicted in Fig. 4, the impact of colorant elimination is influenced by the pH level. Various adsorption experiments were conducted within the pH range of 2-10, spanning a duration of 60 minutes, utilizing three adsorption doses (0.5, 1.0, 2.0, and 3.0 g/L), while maintaining the original colorant concentration at 50 mg/L. The removal percentage of colorants rises with an elevation in pH, reaching its peak (87%, 89%, 91%, and 92% for adsorbent quantities 0.5,1.0, 2.0, and 3.0 g, respectively) at approximately pH 6.0. Nevertheless, the adsorption efficiency diminishes as the pH is further increased.

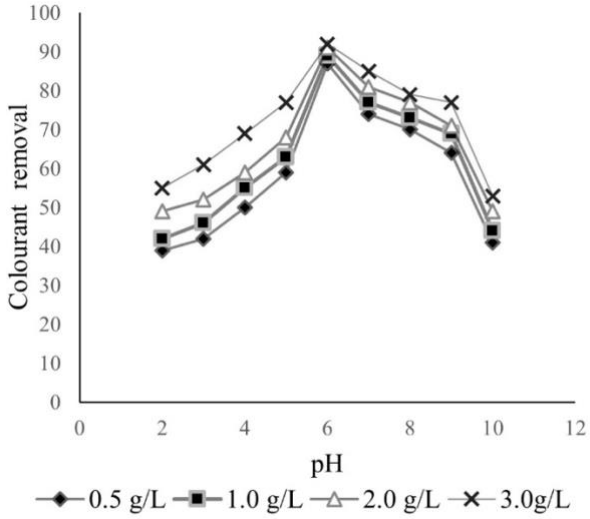

Fig. 4. Effect of pH of solution
S = 180 rpm, M_{ads} = 0.5, 1.0, 2.0, 3.0 g/L, C_i = 50 mg/L, t = 60 min, T = 25 °C, V = 0.25 L

The maximum adsorption is observed at pH ~ 6.0.

3.4 Adsorption isotherms

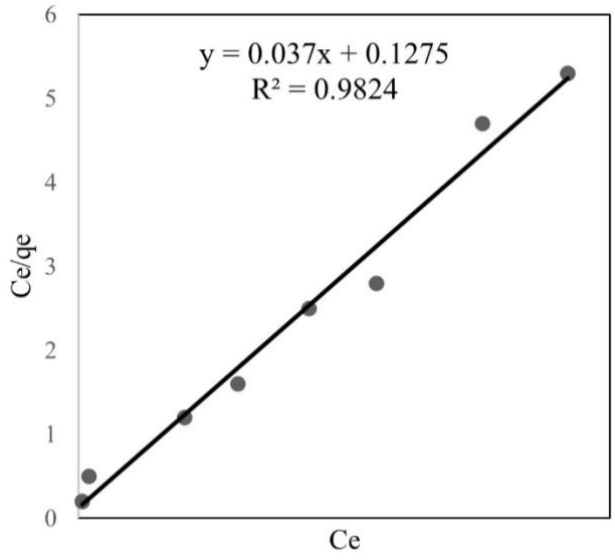

Fig. 5. Langmuir isotherm model.
M_{ads}: 0.5 g, C_i: 25, 50, 75, 100, 150, 200, 250, 300 mg/L. t: 1 hr, T: 25 °C, pH: 7, S: 180 rpm, volume of solution: 0.25L

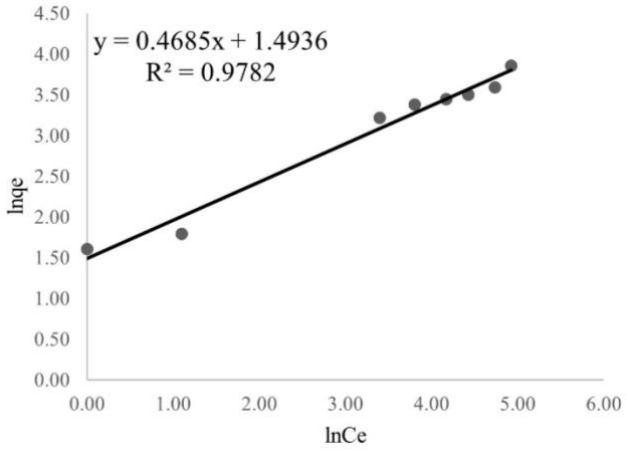

Fig.6. Freundlich isotherm model
M_{ads}: 0.5 g, C_i: 25, 50, 75, 100, 150, 200, 250, 300 mg/L, t: 1 hr, pH: 7, S: 180 rpm, T: 25 °C, volume of solution : 0.25L

Table 1. Langmuir adsorption isotherm

q_e(mg/g)	K_L (L/mg)	R^2	R_L
26.99	0.88	0.9824	0.0206 - 0.1739

Table 2. Freundlich adsorption isotherm

1/nF	K_F (L/mg)	R^2
0.24	1.96	0.9435

For the adsorption of DSDCBS on activated carbon, the adsorption process involved stirring a mixture of DSDCBS and activated carbon for 1 hour at a rotational speed of 180 rpm using a magnetic stirrer. Isotherm investigations were conducted over a concentration range of 25-200 mg/L, utilizing 0.5 g of potato leaves, maintaining a pH of approximately 6, and operating at a temperature of 25 °C. Employing the same procedure as the adsorption study, the percentage of colorant removal, the quantity of colorant adsorbed, and equilibrium concentration values were determined.

The process of fitting experimental data to isotherm equations involves evaluating the degree of alignment between the observed data and the mathematical models used to describe adsorption behavior. In this study, the Langmuir and Freundlich isotherm models were considered, and the fitting process involved comparing the predictions of these models with the actual experimental results.

The Langmuir isotherm model is typically expressed by Equation (3), and the Freundlich isotherm model by Equation (5). These equations include parameters that are determined through the fitting process, and the goodness of fit is commonly evaluated using the coefficient of determination (R^2).

In the described study, the Langmuir model was determined to offer a superior fit to the adsorption data, demonstrated by a higher R^2 value compared to the Freundlich model. This suggests that the Langmuir model provides a more accurate representation of the adsorption behavior under the specified conditions. Detailed information on the specific adsorption parameters obtained during the fitting process, along with their corresponding R^2 values, is presented in Table 1 and 2.

The superior fit of the experimental data to the Langmuir isotherm model suggests monolayer adsorption, indicating that the adsorbate molecules are adsorbed onto the adsorbent surface in a single layer. Conversely, the lower R^2 value in the Freundlich isotherm model is attributed to non-linear adsorption behavior, indicating that the adsorption process does not strictly adhere to the assumptions of the Freundlich model, which describes heterogeneous adsorption onto a surface with multiple layers.

Fig. 7 illustrates R_L plotted against C_i to characterize the favorability of colorant adsorption onto activated carbon using the Langmuir isotherm model. The maximum R_L value of 0.173 was observed at 25 mg/L, decreasing to 0.02 at 250 mg/L concentration. Across the concentration range, R_L values consistently indicate favorable colorant adsorption onto activated carbon. Additionally, consistent with the Langmuir isotherm model, the Freundlich isotherm model also supports favorable colorant adsorption, as evidenced by the obtained 1/nF value being less than 1. The Langmuir isotherm model demonstrated a better fit to the experimental data, suggesting that the adsorption process followed a monolayer adsorption mechanism, which is often associated with favorable and efficient adsorption.

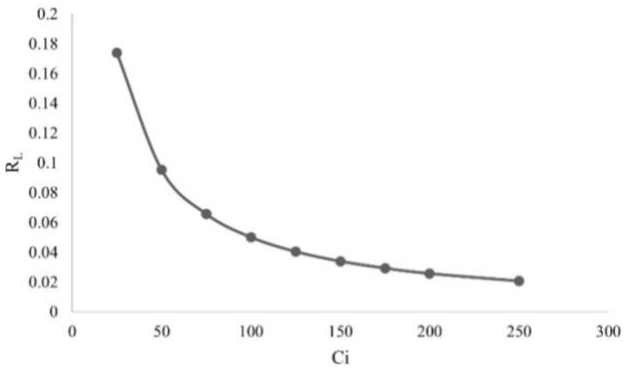

Fig. 7. separation factor (R_L) against Ci.
M_{ads}: 0.5 g, t: 60 min, S: 180 rpm, Ci: 25, 50, 75, 100, 150,175, 200 and 250 mg/L, T: 25 °C, pH:7, volume of solution : 0.25L

4. CONCLUSION

The study suggests that activated carbon obtained from potato leaves possess notable adsorption capabilities for colorant removal from water. Additionally, about 90% of the potato leaves can be recovered through subsequent acid and base treatments, enabling their reuse in further colorant adsorption processes. The Langmuir isotherm model demonstrated a good fit to the experimental adsorption data, implying that the colorant removal using potato leaves involves a favorable chemisorption process.

In summary, activated carbon obtained from potato leaves emerges as a good natural adsorbent for colorant removal, boasting advantages such as environmental friendliness, renewability, and potential cost-effectiveness. However, to maximize their efficacy in wastewater treatment and colorant removal applications, it is crucial to optimize conditions and gain a deeper understanding of the specific interactions between colorants and the adsorbent. This pursuit of sustainable alternatives holds significant promise for addressing environmental challenges while advancing effective water treatment solutions.

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