Cost Effective Removal of Dyes Using Enhanced Adsorption Strategies for Sustainable Environmental Applications

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Abstract. Chemical impregnation with H_2SO_4 solution produces activated carbon from exhausted tea wastes. The adsorption behaviour of activated carbon towards Acid Blue 92 (acidic dye-AB92) is examined in this work. The research used the batch adsorption approach to investigate the impact of key factors such contact time, preliminary dye concentration, and temperature. To understand the reaction process, the kinetic data was performed using pseudo first order, second order, and elovich models.The pseudo second order kinetic mechanism was found to be appropriate for the materials based on the correlation coefficient value (R^2). The Langmuir followed by Freundlich models were used to analyses the isotherm data. Thermodynamic parameters were determined as well. The results revealed that the prepared activated tea waste carbon from teawaste materials is a very effective adsorbent for AB92 adsorption.

Keywords: Activated Tea Waste Carbon, H_2SO_4 impregnation, Acid Blue 92, Kinetic, Equilibrium, Thermodynamic studies

1. Introduction

Synthetic dyes are widely utilized in a wide range of industries, including textiles, printing, and decorating [1]. When wastewater from textiles finds its way into a body of water, it can reduce the amount of dissolved oxygen and prevent aquatic life from reproducing. [2, 3]. Many of the effluents contained in wastewater cannot be degraded or eliminated. As a result, before discharging wastewater into natural water bodies, these contaminants should be eliminated from the wastewater using an appropriate physicochemical treatment process. Toxic and persistent contaminants in wastewater can be eliminated utilising a variety of sophisticated oxidation technologies, including Fenton's, photo-Fenton, Fenton-like, and electrochemical oxidation. However, high energy and chemical requirements remain the main financial roadblocks for

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sophisticated oxidation processes. A non-destructive adsorption method is also suggested for the removal of various organic and inorganic pollutants from wastewater.

The high cost of commercial activated carbon (CAC), which is sourced from non-renewable coal and other petroleum products, is a major barrier to its widespread deployment. The key study focuses on adsorbent selection and mechanism examination. Biomass, especially that derived from forestry and agriculture residues, is a very desirable resource for adsorbents because to its abundance and affordability. [4-14].

Commercially accessible activated carbons are costly, and their application necessitates a significant regeneration and reactivation process. The progressive loss of activated carbon during regeneration can have a significant impact on the process's economic feasibility. It is unreasonable to employ highly structured and resilient activated carbons based on pricey starting materials. As a result, additional sources of materials for activated carbons are being investigated. For a long time, cellulosic and lignocellulosic Wastes are now recognized as the primary raw materials for more effective activated carbon synthesis.All of these activated carbons have been effectively employed for dye waste adsorption. Tea trash is used as the main adsorbent in water treatments after it was shown in recent years to be a highly efficient precursor to creating activated carbon due to its high carbon content. [15]. One of the carbonaceous sources that is most abundantly accessible on Earth is tea detritus, which yields extremely adsorptive activated carbon. The primary aim of this study was to produce activated carbon from tea waste using an economical and straightforward method, and subsequently evaluate its adsorption capacity for water treatment on a small-scale basis.

2. Materials and Methods

2.1 Preparation of Adsorbent

Tea waste is collected from local tea stores in the Erode district. It was pulverized, dried, and washed with double distilled water. 1:1 molar ratio of tea waste and 5g of weighed dried tea waste and N sulfuric acid mixture are heated and cooled to room temperature. Then the precipitate was washed a number of times with double distilled water and kept in a muffle furnace at 150°C for five hours. Finally, the obtained materials are used as an adsorbent. [16].

2.2 Properties of Adsorbate

The adsorbate was a commercially available acid blue 92 dye. The batch adsorption experiments were carried out at 30°C. Throughout the experiment, a fixed amount of adsorbent is combined with a known starting concentration of Acid Blue 92 solution, and the mixture is agitated. The amount of Acid Blue 92 left in the filtrate after the adsorbent and adsorbate were filtered was determined using spectrophotometry. AB-92 dye has a maximum wavelength of 571 nm.(Fig.1)

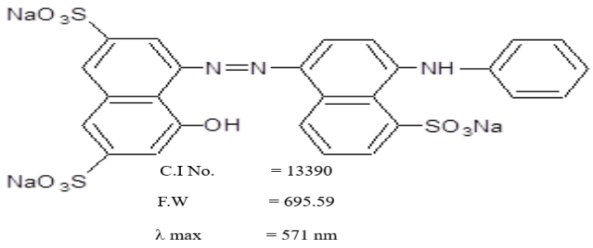

Fig. 1. Structure of Acid Blue 92

3 Result and Discussions

3.1 Effect of Agitation time

The uptake of Acid Blue 92 from water by activated tea waste carbon increased from 31.6 to 94.75 percent when the agitation time was varied from 10 to 160 minutes, and reached equilibrium in 140 minutes at 30°C and pH 7.0 when the initial concentration of the Acid Blue 92 solution used was 20 ppm and the adsorbent dosage was 100mg. The increased intra-particle diffusion that takes place during prolonged shaking durations may be the cause of the rise in Acid Blue 92 adsorption with increasing agitation duration. (Figure-2). Rao and Bhole noticed a similar result in the elimination of Acid Blue 92 by fly ash and bagasse [17].

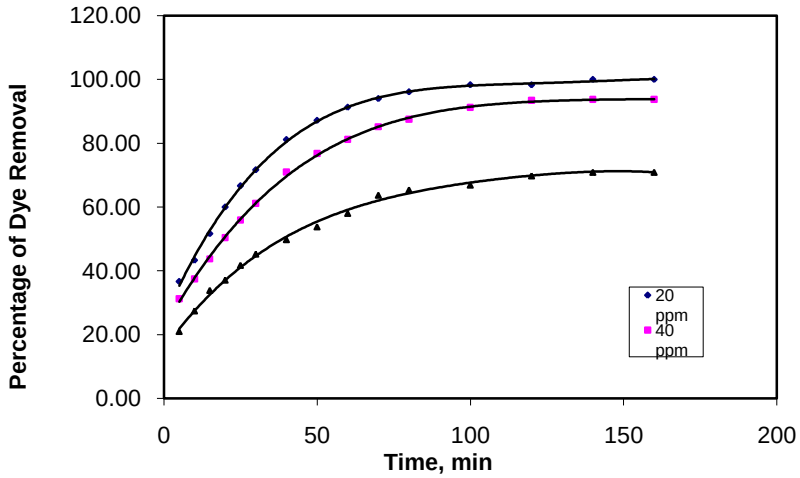

Fig. 2. Effect of Agitation Time on dye removal

3.2 Effect of initial concentration of Acid Blue 92 Solution

The starting concentration of Acid Blue 92 solution was adjusted (20, 40, and 60 ppm), and batch adsorption studies with 100mg of the adsorbent were performed at 30°C and pH 7.0. The percentage of Acid Blue 92 removed increased from 75 to 94.75 percent with 100 mg of the adsorbent over an agitation period of 160 minutes when the initial concentration of the Acid Blue 92 solution was adjusted from 20, 40, and 60 ppm. For a lesser number of adsorbate species, the existence of more active centers on the adsorbent's surface may account for the higher absorption of Acid Blue 92 at low concentrations.The adsorption curves for Acid Blue 92 are single, smooth, and continuous, indicating that dye molecules may be covered in a monolayer on the adsorbent's surface. Mise and Rajamanya found a similar result in the removal of Cr(VI) from dried stem of Jowar using activated carbon [18].

4 Kinetic Modeling

4.1 Lagergren (Pseudo First Order Equation) Model

The findings of Acid Blue 92 adsorption on Tea waste carbon are shown in Figure 3 as a pseudo first order plot of the Lagergren equation. For the whole sorption time in this case, a linear relationship was discovered between ln(qe-qt) and agitation length, with a good correlation coefficient (> 0.998) for every line (Table 1). It is clear that the kinetics of Acid Blue 92 sorption on Tea rubbish can be explained by a pseudo first order equation. The pseudo first order equation is useful for very heterogeneous systems, as the adsorption of Acid Blue 92 on to Tea debris, even if it does not provide any mechanistic proof.

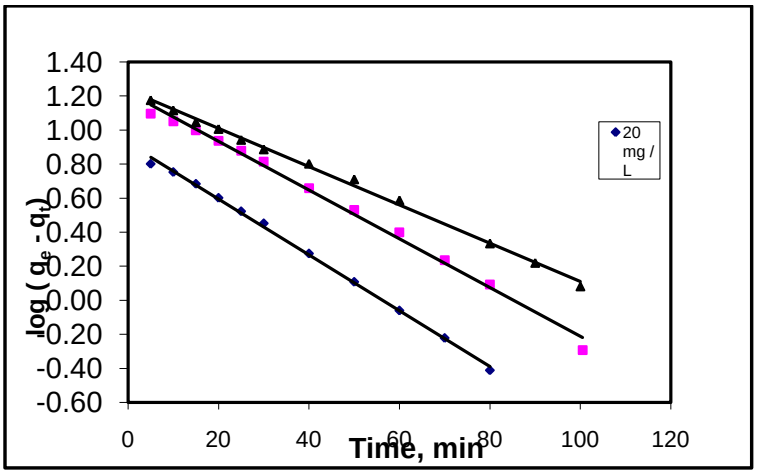

Fig. 3. Lagergren Plot

4.2 Elovich Model

Figure-4 depicts the results of the sorption of Acid Blue 92 on to Tea debris using the Elovich Equation at varied initial dye concentrations (Viz. 20 ppm, 40 ppm, 60 ppmThe graph showed a linear relationship between ln(t) and qt, the amount of Rhodamine–B adsorbed. These graphs showed distinct linear zones within certain datasets.. As a result, in many circumstances, several regressions on distinct data ranges were required. The Elovich model could not be used to estimate the kinetics.

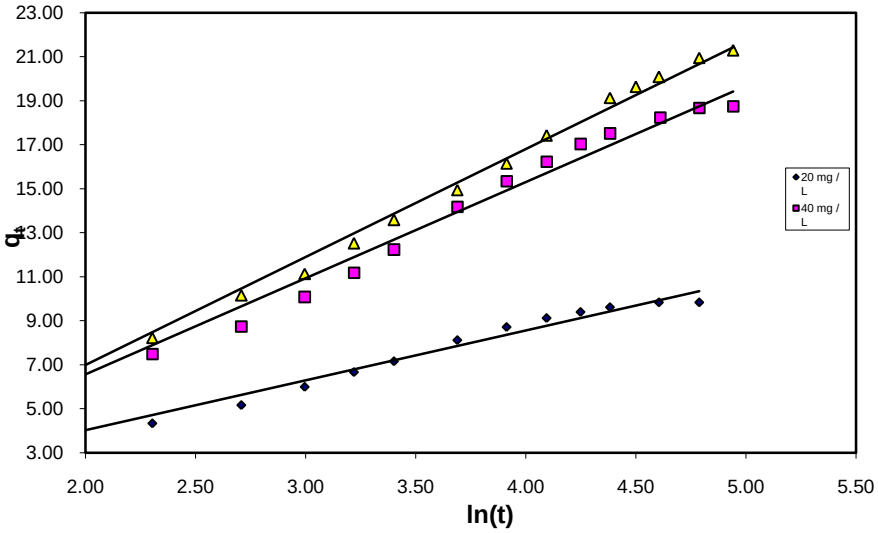

Fig. 4. Elovich Plot

4.3 Pseudo Second Order Model

Pseudo-second-order equations depict the identical data in Figure-5. These graphs illustrate that when When the pseudo-second order equation was applied, correlation was seen in the data fitscorrelation strong coefficients (> 0.987), and it was feasible to determine if the rate-determining process is a chemical reaction from them. When the initial dye concentration is raised from 20 to 60 ppm, the amount of Acid Blue 92 that is adsorbed rises with time. A more effective use of the sorbent's sorptive capabilities is predicted with higher Initial Concentration values, since the sorption driving force is strong.

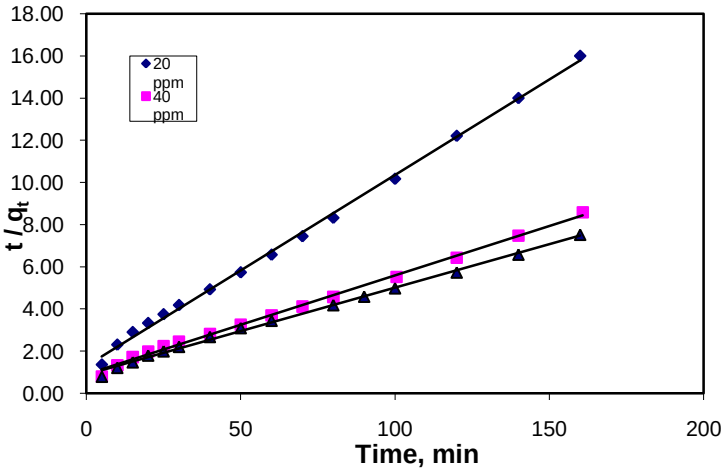

Fig. 5. Pseudo second order plot

Table 1. Kinetic Model Values for the Adsorption of Acid Blue 92 on to Tea waste Activated Carbon

Concentration	**Pseudo First Order Values**		**Elovich Values**			**Pseudo Second Order Values**			
	k_L x10^{-2}	r^2	**α**	**β**	r^2	q_e	k_2x10^{-3}	**h**	r^2
20 ppm	3.777	0.998	1.814	0.441	0.988	11.098	6.192	0.763	0.975
40 ppm	3.293	0.998	0.978	0.229	0.987	21.322	2.442	1.110	0.975
60 ppm	2.579	0.997	1.017	0.204	0.991	24.272	1.902	1.121	0.989

4.4 Isotherm Modeling

Figure 6 shows the Langmuir adsorption isotherm produced after 160 minutes of agitation. Langmuir adsorption isotherms may be used based on the values of RL1 found in this investigation.

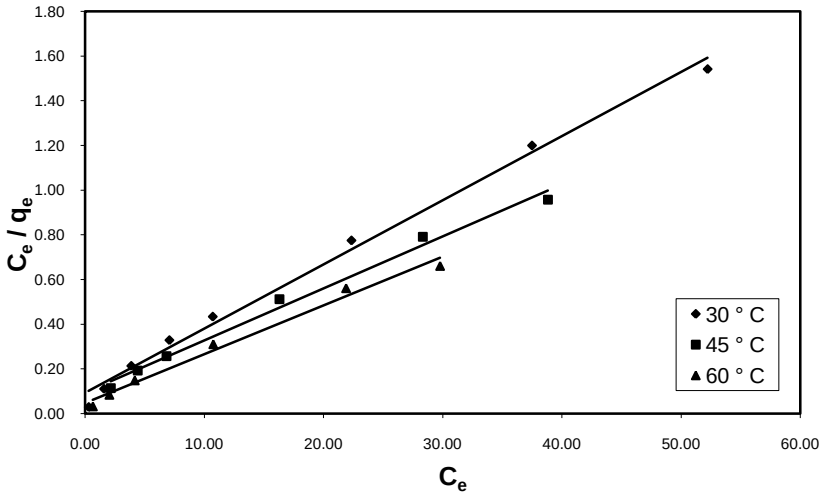

Fig. 6. Langmuir Plot

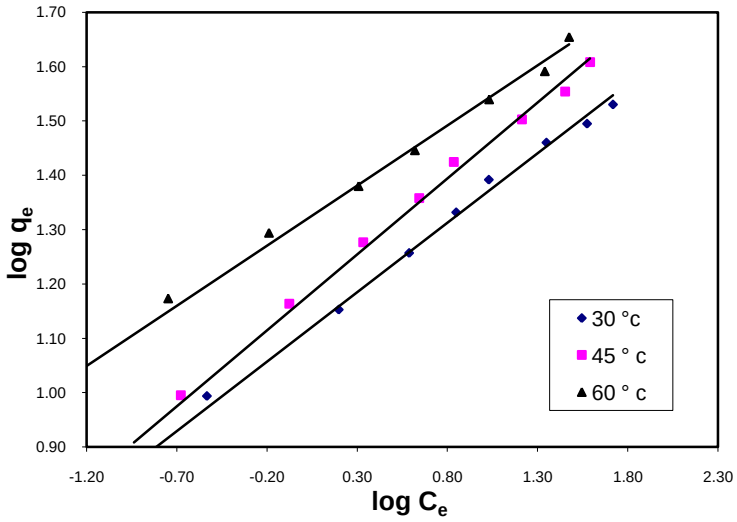

Fig. 7. Freundlich Plot

Figure 7 shows that this adsorption isotherm used to a wide range of adsorption conditions. Table 2 lists the values of k_f. Increasing temperatures have been shown to decrease adsorption capacity in studies looking at the freundlich parameters. The adsorption intensity, on the other hand, is quite stable. These facts can be used to make practical design changes.

Table 2. Parameters of Langmuir and Freundlich Adsorption Isotherms for Acid Blue 92 onto Activated Tea waste Carbon.

Temperature ° C	Langmuir Isotherm			Freundlich Isotherm		
	b , L / mg	Q_o, mg / g	R_L	1/n	n	k_f
30	0.3361	34.60	0.129	0.2077	4.8146	14.625
45	0.2608	42.73	0.160	0.2429	4.1169	16.334
60	0.4523	45.87	0.099	0.2110	4.7393	21.043

4.5 Thermodynamic Parameters

Vant Hoff plots (1/T versus Kc) were used to determine the slope and intercept of H and S, as shown in Figure-8. Acid Blue 92 solution batch adsorption tests were carried out at a pH 7.0 and at a pH 7.0 by altering the temperature (303K, 318K and 333K). 100 mg of the adsorbent was employed to keep the starting concentration of Acid Blue 92 solution at 20 ppm. Adsorption of Acid Blue 92 is represented in Table 3 by the following values: G, S, H The adsorption of Acid Blue 92 species is possible and spontaneous because of the negative values of the free energy change (G) [19]. The adsorption of Acid Blue 92 on activated Tea waste seed shell waste carbon seems to be exothermic because of the negative H values. Acid Blue 92 adsorption causes an increase in unpredictability, which is why S is positive [20].

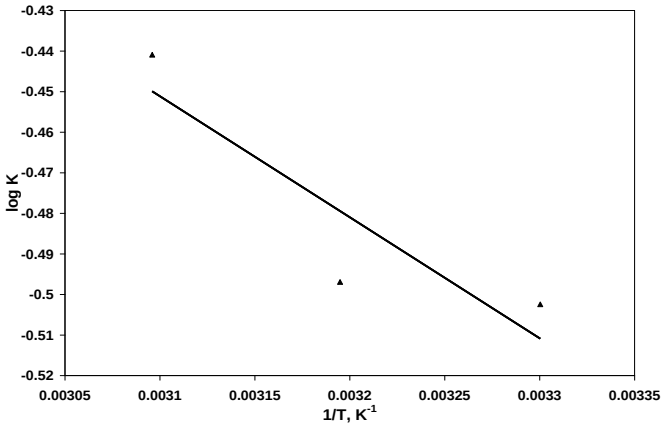

Fig. 8. A Plot of 1/T Vs log K

Table 3. Thermodynamic Parameters for the Adsorption of Acid Blue 92 on to Activated Tea waste Carbon.

Temperature in Kelvin	**ΔG , J mole^{-1}**	**ΔS , J mole^{-1}**	**ΔH , KJ mole^{-1}**
303	- 972.82	26.84	- 9.122
318	- 593.82		
333	- 149.50		

5. Conclusion

Acid Blue 92 adsorption on activated Tea waste carbon has been studied in this work. It is important to note that the adsorption of Acid Blue 92 is dependent on the concentration and agitation duration. At 160 minutes, the adsorption of Acid Blue 92 approaches equilibrium. According to the Elovich model, the acid blue 92 sorption on tea waste is best described by the pseudo first order and pseudo second order equations, yet compared to the pseudo second order equation, the pseudo first order correlation coefficient is larger. Since the pseudo first order equation has a greater correlation coefficient than the pseudo second order equation, it was determined that it would be the most appropriate. The Langmuir and Freundlich adsorption isotherms can be used to connect equilibrium adsorption data. Based on Enthalpy change values, the adsorption of Acid Blue 92 onto activated Tea waste carbon is an exothermic process. Thus, the results of this study show that the Tea waste carbon is a low-cost adsorbent for the removal of Acid Blue 92 from aqueous solution.

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