



Sorption Dynamics and Equilibrium Uptake of Reactive Blue 2 using Activated Carbon Prepared from Agricultural Waste: *Jatropha Curcas* Stem

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ABSTRACT

The feasibility of activated carbon prepared from *Jatropha Curcas* stem waste to remove Reactive Blue 2 from aqueous solution was investigated through batch mode contact process. The effect of various experimental parameters, such as initial dye concentration (20mg/L), pH 6.5, adsorbent dosage 50mg and Temperature 30 °C was investigated in a batch mode-adsorption technique, the optimum condition for removal of Reactive Blue 2 Dye was found to be pH 6.5. The equilibrium data were best represented by the Langmuir isotherm model, with maximum mono layer adsorption capacity. The kinetic data were fitted to pseudo first order, pseudo second order and intra particle diffusion models and it was found to follow closely the pseudo second order kinetic model.

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Introduction

Industrial and Textile effluents are known toxicants, which inflict acute disorders in aquatic organisms. Uptake of textile effluents through food chain in aquatic organisms may cause various physiological disorders like hyper tension, spordiac fever, renal damage, cramps etc¹. Reactive Blue 2 is one such effluent which causes various disorders when present in aqueous solution. Hence the treatment of waste water containing Reactive Blue 2 is a challenging problem. Adsorption using activated carbon is one of the efficient procedures for treatment of waste water². Cellulosic and Lignocellulose wastes have long been recognized as starting materials for the preparation of activated carbon^{3,4}, Ipomoea Carne⁵, Several low cost carbon and non conventional adsorbents have been used. Adsorbents used include fly-ash⁶, Sterculia Quadrifida shell⁷, Wollastonite⁸, *Jatropha Curcas*⁹, Multi-Walled Carbon Nanotubes¹⁰, Saw dust and rice husk with coir pith carbon¹¹, Pomegranate Peel¹² etc.

The *Jatropha Curcas* plant belongs to the Euphorbiaceae family, a drought resistant shrub or tree which is widely distributed in the wild or semi-cultivated areas in Central and South America, Africa, India and South East Asia^{13,14,15}.

The scientific name of physic nut is "*Jatropha curcas*". The genus name *Jatropha* derives from the Greek word *jatr'os* (doctor) and *troph'e* (food), which implies medicinal uses¹⁶. The medicinal uses of this species range from external, internal and even teeth¹⁷. Different parts of the plant including the leaves, fruits, latex and bark contains glycosides, tannins, phytosterol, flavonoids and steroidal sapogenins that exhibits wide range of medicinal properties^{18,19,20}. The *Jatropha Curcas* Stems of young leaves have been used to successfully treat urinary infections. The tender twig can also be used as a tooth brush to clean the teeth²¹. The oil extracted from the seed can be utilized as a biodiesel feed stock and in soap production. During the World War II²², the *Jatropha* seed oil was used as a diesel substitute.

The leaves are used in traditional medicine against coughs or as an antiseptic²³. The extraction of oil can be used as an organic fertilizer. *Jatropha curcas* oil is non-edible due to the presence of anti-nutritional factors such as phorbol esters²⁴.

The present work is to report the result of the feasibility study of utilizing *Jatropha Curcas* stem waste as an adsorbent for the removal of Reactive Blue 2 in aqueous solution.

Materials and Methods

Jatropha Curcas stem waste is collected; it was dried, charred with excess quantity of 10% solution of zinc chloride for 24 hours. Then the resultant carbon is washed with excess quantity of distilled water and dried at 110 °C for 1hour. To eliminate surface groups and thermal activation, the carbonized material was treated at 750 °C for 60 minutes in a furnace. The resulting carbons were ground in a mill, washed with pure water and finally dried at 120 °C. The dried powders were sieved in the size range from 125-250 µm.

Kinetics Models

In order to investigate the mechanism of sorption and potential controlling steps such as mass transport, several kinetic models were tested including the pseudo first order kinetic model, Elovich model and pseudo second order kinetic model for a batch contact time process, where the rate of sorption of dye on to the given adsorbent is proportional to the amount of dye sorbed from the solution phase.

Pseudo First Order Kinetic Model

A simple kinetic analysis of adsorption, the Pseudo first order kinetics and its integrated form, is given by²⁵

$$\log (q_e - q_t) = \log q_e - \frac{k_L}{2.303} t \quad (1)$$

Where k_L is the pseudo first order rate constant that is calculated from the slope of the plot of $\log (q_e - q_t)$ vs time (Fig.1). A plot of $\log (q_e - q_t)$ vs time enables calculation of the

rate constant k_1 and from the slope and intercept of the plot, q_e (pred) can be calculated.

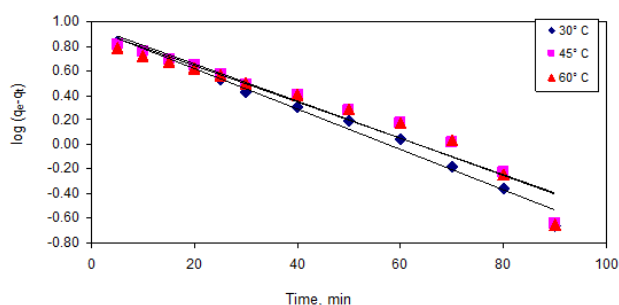


Fig 1. Pseudo First Order Plot

Elovich Model

The Elovich or Roginsky-Zeldovich equation is generally expressed as follows²⁶,

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad (2)$$

Where,

q_t = The amount of dye adsorbed in mg/g, at time t .

α = the initial dye sorption rate, mg/g. min.

β = the adsorptions constant, g/mg during the experiment.

To simplify the Elovich equation, Chien and Clayton²⁷ assumed $\alpha\beta \gg 1$, and on applying the boundary conditions $q_t = 0$ at $t = 0$ and $q_t = q_t$ at $t = t$, the above equation becomes,

$$q_t = \frac{1}{\beta} \ln(\alpha \beta) + \frac{1}{\beta} \ln t \quad (3)$$

Thus the constants α and β can be obtained from the slope and intercept of linear plot of q_t versus $\ln t$ (Fig. 2). The above equation will be used to test the applicability of the Elovich equation to the kinetics of chosen adsorbent adsorbate system.

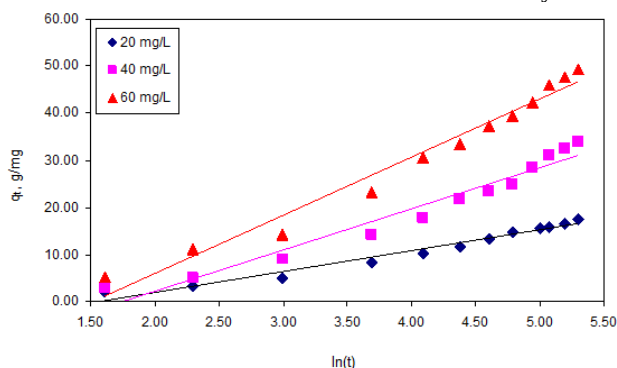


Fig 2. Elovich Plot

Pseudo Second Order Kinetic Model

To describe dye adsorption, the modified pseudo second order kinetic equation is expressed as²⁸

$$t/q_t = \frac{t}{k_2 q_e^2} + \frac{1}{q_e} t \quad (4)$$

Where, k_2 is the pseudo second order rate constant.

A plot of t/q_t vs t (Fig. 3) enable calculation of the rate constant k_2 which in turn is used to calculate the initial sorption rate h as follows

$$h = k_2 q_e^2 \quad (5)$$

The q_e value calculated from the pseudo second order model system is in good agreement with the experimental q_e values.

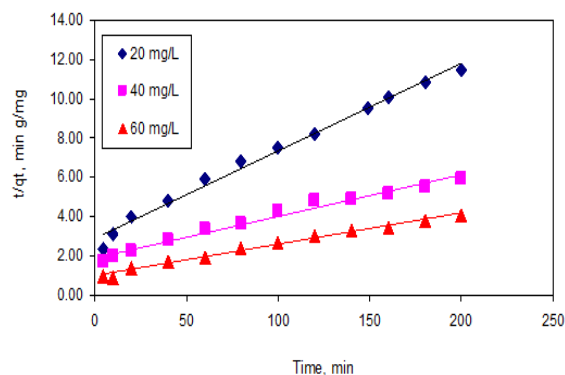


Fig 3. Pseudo Second Order Plot

Isotherm Studies

Langmuir Isotherm

The Langmuir adsorption isotherm is based on the assumption²⁹ that an adsorbent adsorbs the dye at specific homogeneous sites and once that site is occupied, no further adsorption take place at that site. Theoretically, the adsorbent has a finite capacity to absorb the adsorbate and hence there is a limit beyond which no further adsorptions can occur³⁰. The monolayer capacity can be represented by the expression:

$$q_e = Q_0 k_L C_0 / 1 + k_L C_e \quad (6)$$

The linear form of the above equation is represented as:

$$C_e / q_e = 1/Q_0 k_L + C_e / Q_0 \quad (7)$$

Where, k_L is related to the free energy of adsorption (L/mg) and q_0 is the maximum adsorption capacity. The value of Q_0 and k_L were calculated from the slop and intercept of the linear plot (Fig. 4). The equilibrium concentration and hence the amount of dye adsorbed were calculated by varying the dye concentration between 20mg/L and 60mg/L with a fixed adsorbent dose and all other experiment condition kept constant.

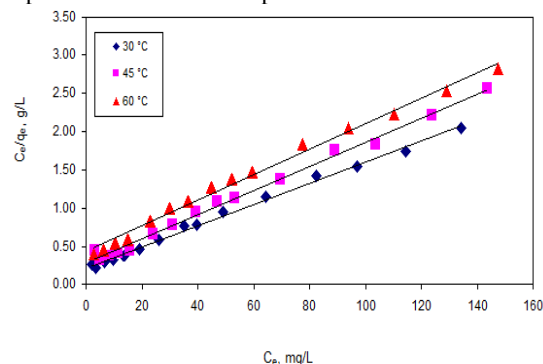


Fig 4. Langmuir Plot

The isotherm constants for the Langmuir isotherm under study were calculated from the linear form of the model and the correlation coefficients are given in Table 3. The essential characteristics of Langmuir isotherm can be expressed in terms of a dimensionless constant called the equilibrium parameter³¹.

$$R_L = 1 / 1 + K_L \times C_0 \quad (8)$$

The value of R_L indicates the type of isotherm to be favourable ($0 < R_L < 1$), linear ($R_L = 1$), unfavourable ($R_L > 1$) or irreversible $R_L = 0$, where K_L is the Langmuir constant and C_0 is the highest initial dye concentration (mg/L).

Freundlich Isotherm

Freundlich isotherm is an empirical equation employed to describe heterogeneous system. the Freundlich Equation is commonly given by³²

$$q_e = k_f C_e^{1/n} \quad (9)$$

Where, q_e is the amount of solute adsorbed per unit weight adsorbed (mg/g), C_e the equilibrium concentration of solute in the bulk solution (mg/L), k_f and n are Freundlich constant

indicated the relative adsorption capacity and sorption intensity of the adsorption (mg/g). A linear form of the Freundlich expression can be obtained by taking logarithms of the nonlinear form and can be written as

$$\log q_e = (1/n) \log C_e + \log k_f \quad (10)$$

The Freundlich constant k_f and n can be calculated from the slope and intercept of the linear plot with $\log q_e$ vs $\log C_e$ (Fig. 5).

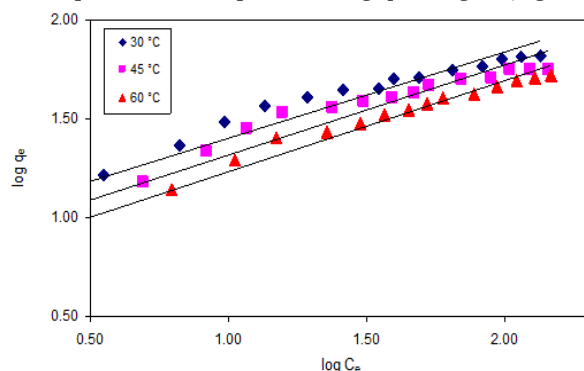


Fig 5. Freundlich Plot

Adsorption Thermodynamics

Any chemical system tends to attain a state of equilibrium from one of non - equilibrium. The thermodynamic parameters, which characterize the equilibrium of the system are the Gibbs free energy change ΔG , the enthalpy change ΔH and the entropy change ΔS . These parameters were determined using the following relations³³,

$$K_c = C_{Ae} / C_e \quad (11)$$

$$\Delta G^\circ = -RT \ln K_c \quad (12)$$

$$\log K_c = \Delta S / 2.303R - \Delta H / 2.303RT \quad (13)$$

Where K_c is the equilibrium constant, C_{Ae} is the solid phase concentration at equilibrium,

C_e is the residual concentration at equilibrium, R is the gas constant in J/mole and T is the temperature in Kelvin.

Results and Discussion

Effect of pH on Reactive Blue 2 removal

The pH is an important controlling parameter in the adsorption process and thus the role of hydrogen ion concentration was studied for the adsorption of Reactive Blue 2 at different pH, covering a range of 5.5 to 7.5 at 30 °C. Batch experiments were conducted. The initial concentration of the Reactive Blue 2 solution used was 0.1 mg/50 ml with 50 mg of the adsorbent. The Removal of Reactive Blue 2 was found to be maximum at a pH of around 5.5 to 7.5. At lower pH the large numbers of H^+ ions neutralizes the negatively charged coal surface or convert a neutral group to be positively charged.

Effect of initial concentration of Reactive Blue 2 solutions

The initial concentration of Reactive Blue 2 solution was varied (20, 40 and 60 mg/L) and batch adsorption experiments were carried out with 50mg of the adsorbent at 30 °C and at pH 6.5. An increased percentage removal of Reactive Blue 2 from 75 to 85 % was observed with 50mg of the adsorbent (Fig. 6), when the initial concentration of the Reactive Blue 2 solution was varied from 10 mg/L to 80 mg/L. The higher uptake of Reactive Blue 2 at low concentration may be attributed to the availability of more active centers on the surface of the adsorbent for lesser number of adsorbate species. It is also observed that the actual amount of dye adsorbed increase with increases in initial dye concentration (C_0) is due to increase in the interaction between the adsorbent and Adsorbates, therefore an increase in the amount of dye adsorbed for unit weight of adsorbent.

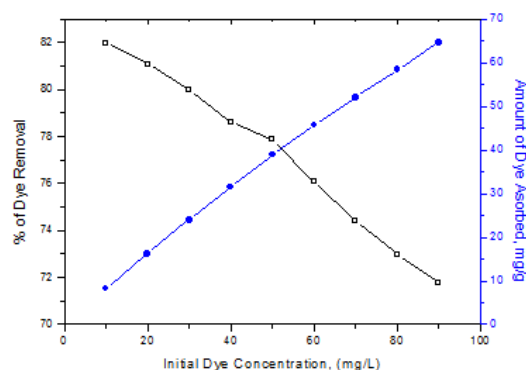


Fig 6. Effect of Initial dye concentration of Reactive Blue 2 Solution

Effect of temperature of Reactive Blue 2 solutions

Temperature influences the Reactive Blue 2 adsorption properties of dried *Jatropha Curcas* stem waste. The temperature effect on the bio sorption capacity of dried *Jatropha Curcas* stem waste was examined at 30, 45 and 60 °C using initial dye concentration of 20mg / L at pH 7. The adsorption capacities of the activated *Jatropha Curcas* stem waste increases with decreasing temperatures from 60 to 30 °C, which indicates that the adsorption process is exothermic. The optimum temperature for dye adsorption of the dried *Jatropha Curcas* within the temperature range studied was found to be 30 °C.

Effect of Adsorbent Dosage

The amount of dye adsorbed (mg/g) and the percentage of dye removal with increases in adsorbent dosage is shown in Fig 7. The carbon dosage was varied in the range of 0.02 to 0.10g and the adsorption of Reactive Blue 2 for a dye concentration of 80mg/L was studied.

The percentage of dye removal increased from 59.52 % to 84.20 % for an adsorbent dosage of 0.02 to 0.10g. This is due to the increased surface area and available of more adsorption sites. An adsorbent dosage of 0.10g was required to attain 84.20% dye removal. When the adsorbent and the solute concentration are low then the adsorption rate is low on the other hand. When the adsorbent to the solute concentration is high then the adsorption is more on to the adsorbent surface and hence there is a decrease in the solute concentration in the solution. At high adsorbent to solute concentration, the adsorption is high on the adsorbent surface and hence the solute concentration in the solution decreases. This is due to the adsorption of a fixed amount of dye on a fixed mass of the adsorbent.

Kinetic Modeling

Pseudo First Order Equation

Fig. 1 shows a plot of Pseudo First Order Equation for the results of adsorption of Reactive Blue 2 from 20 mg/L to 60 mg/L between $\ln (q_e - q_t)$ and agitation time over whole sorption period with high correlation coefficient (>0.98) for all the lines (Table 1). It is clear that the pseudo first order equation may be used to describe the kinetics of sorption of Reactive Blue 2 on to *Jatropha Curcas* Although the Pseudo First Order Equation does not provide any mechanistic evidence, it has been proved suitable for highly heterogeneous systems of which the adsorption of Reactive Blue 2 on *Jatropha Curcas* stem waste is undoubtedly such a case.

Elovich Model

The results of the sorption of Reactive Blue 2 on to *Jatropha Curcas* stem waste has been represented in the form of Elovich Equation in Fig. 2 at various Initial dye concentrations (viz 20mg/L, 40mg/L, 60 mg/L). From the plot a linear relationship between the amount of Reactive Blue 2

adsorbed, qt and $\ln(t)$ was established. These plots showed different distinct linear regions within individual sets of data. In these cases, it was thus necessary to perform multiple regressions on different ranges of the data. The kinetics could not be approximated using Elovich model.

Pseudo Second Order Model

The same data are shown as pseudo second order equations in Fig. 3 These plots show the data fits had good correlation coefficients (>0.978) when the pseudo second order equation was employed. It was possible to ascertain from them whether the rate determining process is a chemical reaction. Thus, increasing the initial dye concentration from 20 mg/L to 60 mg/L the Reactive Blue 2 sorbed at any contact time increases. This is obvious for higher Initial Concentration values, as a more efficient utilization of the sorptive capacities of the sorbent would be expected due to greater sorption driving force.

The corresponding linear plots of the values of q_e , k_2 and h against C_0 were regressed to obtain the expressions for these values in terms of the initial Reactive Blue 2 concentration, C_0 with high correlation coefficient (>0.992).

Isothermic Modelling

The Langmuir adsorption isotherm obtained in 160 minutes of agitation time is shown in the Fig. 4 The values of $R_L < 1$, obtained in this study indicates the applicability of Langmuir adsorption isotherm.

The values of absorption intensity $1/n \ll 1$ reveals the applicability of the Freundlich adsorption isotherm. The values of $1/n$ and k_f are given in the Table 3. The study of temperature effects on the Freundlich parameters reveals a decreasing trend in the adsorption capacity with increase in temperature. However, the variation in the adsorption intensity is negligible. These data are useful for practical design purposes.

Mechanisms for sorption of Reactive Blue 2 on to *Jatropha curcas* stem waste

Because of the high correlation coefficients obtained using pseudo first order pseudo second order and Elovich kinetic models, it was impossible to conclude which adsorption mechanism actually occurred and was responsible for the ability of adsorbent to review other sources of information in an attempt to identify the specific adsorption mechanism.

In adsorption process of Dye ion on the solid surface, the Dye species migrate towards the surface of the adsorbent. This type of migration proceeds till the concentration of the adsorbate species, adsorbed, on to the surface of the adsorbent. Once equilibrium is attained, the migration of the solute species from the solution stops. Under this situation, it is possible to measure the magnitude of the distribution of the solute species between the liquid and solid phases. The magnitude of this kind of distribution is a measure of the efficiency of the chosen adsorbent in the adsorbate species.

When a powdered solid adsorbent material is made in contact with a solution containing Dyes, the Dyes first migrate from the bulk solution to the surface of the liquid film. This surface exerts a diffusion barrier. This barrier may be very significant or less significant. The involvement of a significant quantum of diffusion barrier indicates the dominant role taken up by the film diffusion in the adsorption process. Furthermore, the rate of an adsorption process is controlled either by external diffusion, internal diffusion or by both types of diffusions.

The external diffusion controls the migration of the solute species from the solution to the boundary layer of the liquid phase. However, the internal diffusion controls the transfer of the solute species from the external surface of the adsorbent to the internal surface of the pores of the adsorbent material³⁴.

It is now well established, that during the adsorption of dye over a porous adsorbent, the following three consecutive steps have taken place³⁵

- (i) transport of the ingoing adsorbate ions to external surface of the adsorbent (film diffusion),
- (ii) transport of the adsorbate ions within the pores of the adsorbent except for a small amount of adsorption, which occurs on the external surface (particle diffusion),
- iii) Adsorption of the ingoing adsorbate ions on the interior surface of the adsorbent.

Out of these three processes, the third process is considered to be very fast and is not the rate limiting step in the uptake of organic compounds³⁶. The remaining two steps impart the following three possibilities:

Case 1: External transport $>$ internal transport, where rate is governed by particle diffusion.

Case 2: External transport $<$ internal transport, where the rate is governed by film diffusion.

Case 3: External transport $\approx$ internal transport, which accounts for the transport of the adsorbate ions to the boundary and may not be possible within a significant rate, which later on gives rise to the formation of a liquid film surrounded by the adsorbent particles with a proper concentration gradient.

In the batch mode contact time adsorption experiments, rapid stirring is maintained. This induces Reactive Blue 2 from the solution to the pores of the adsorbent material and this step may control the rate of the adsorption process³⁷.

According to Michelson et al.,³⁸ for the adsorption of Dyes on the carbon surface, for film diffusion to be rate-determining step, the value of the film diffusion coefficient, D_f , should be in the range $10^{-6} - 10^{-8} \text{ cm}^2/\text{sec}$.²⁶ If pore diffusion were to be the rate limiting step, the pore diffusion coefficient, D_p , should be in the range $10^{-11} - 10^{-13} \text{ cm}^2/\text{sec}$. In order to find out the nature of the process responsible for adsorption on to activated *Jatropha Curcas* stem, attempts were made to calculate the diffusion coefficient of the process.

Assuming spherical geometry of the sorbents³⁹, the overall rate constant of the process can be correlated to the pore diffusion coefficient in accordance with the expression,

$$t_{1/2} = 0.03 \frac{r_o^2}{D_p} \text{ or to the film diffusion coefficient in accordance with}$$

$$t_{1/2} = 0.23 \frac{r_o \partial}{D_f} \times \frac{\bar{C}}{C} \quad (14)$$

where r_o is radius of the sorbent (cm), D_p and D_f are pore diffusion coefficient (cm^2/sec) and film diffusion coefficient

(cm^2/sec) respectively, $\frac{\bar{C}}{C}$ is equilibrium loading of the adsorbent, ∂ is the film thickness (cm) and $t_{1/2}$ is the time for half change (sec).

Since the carbon particles used were of the size range (180-250 μm), the average diameter of the particle was taken as $0.0215 \times 10^{-4} \text{ cm}$. using these values, the film diffusion coefficient and pore diffusion coefficient were calculated.

Then considering the pseudo first order rate constant k_L , for the adsorption of Reactive Blue 2, the values of D_p and D_f were calculated under the given set of operating conditions, and are presented in the Table 4.

Table 1. Properties of Reactive blue 2

S.No	Parameter	Value
1	C.I Name	Reactive Blue 2
2	C.I Number	61211
3	Chemical Class	Monoazo
4	Molecular Formula	C ₂₉ H ₁₇ ClN ₇ Na ₃ O ₁₁ S ₃
5	Formula Weigh	776.01
6	λ max	615

Table 2. Kinetic Model Values for the Adsorption of Reactive Blue 2 on to *Jatropha Curcas* stem waste Activated Carbon

Concentration	Pseudo First Order Values		Elovich Values			Pseudo Second Order Values			
	k _{Lager} x10 ⁻²	r ²	A	β	r ²	q _e	k _{Lager} x10 ⁻²	h	r ²
20 ppm	0.0123	0.9973	0.9190	0.2186	0.9687	23.2898	0.0054	0.759	0.9889
40 ppm	0.0128	0.9472	1.5134	0.1096	0.9524	48.6103	0.0008	0.853	0.9808
60 ppm	0.0134	0.9489	2.6760	0.0793	0.9717	63.8391	0.0002	0.875	0.9868

Table 3. Parameters of Langmuir and Freundlich Adsorption Isotherms

Temperature °C	Langmuir Isotherm			Freundlich Isotherm	
	b, L/mg	Q ₀ , mg / g	R _L	1/n	k _f
30	0.0600	78.6838	0.9946	0.4350	9.4208
45	0.0424	76.8719	0.9939	0.4539	7.3152
60	0.0575	63.0808	0.9908	0.4614	5.9284

Table 4. D_p and D_f values for the chosen adsorbent - adsorbate system

S.No.	Dye	Particle Size, μm	t _{1/2} , s	D _p x 10 ⁻¹⁰ , cm ²	D _f x 10 ⁻⁹ , cm ²
1	Reactive Blue 2	75	1026.66	4.40	1.054
		180	1114.74	1.28	1.814
		250	1423.97	2.30	2.313

Table 5. Values of energy of activation E_a, entropy of activation ΔS[#] and pre-exponential constant D₀ for the present study

S.No.	Parameter	Value
1.	Di, cm ² /sec	
	30 °C	3786 X 10 ⁻¹¹
	45 °C	1.2627 X 10 ⁻¹¹
	60 °C	1.0240 X 10 ⁻¹¹
2.	E _a , KJ mol ⁻¹	-9.4634
3.	ΔS [#] , JK ⁻¹ mol ⁻¹	-175.10
4.	D ₀ , cm ² /Sec	9.3223 X 10 ⁻¹²

Table 6. Thermodynamic Parameters for the adsorption of Reactive Blue 2 on to *Jatropha Curcas* stem waste Activated Carbon

S.No	Temperature	ΔG, J mole ⁻¹	ΔS, J mole ⁻¹	ΔH, KJ mole ⁻¹
1	303 K	- 3703.13	-34.09	-14.93
2	318 K	- 3096.71		
3	333 K	-3571.44		

The values of D_p and D_f for all Reactive Blue 2 in the present study are found to be in the order 10⁻¹⁰ to 10⁻¹¹ and 10⁻⁹ to 10⁻¹⁰ cm²/sec which indicates that pore diffusion has some amount of influence in the rate determining step.

Gupta et al⁴⁰, have reported a D_p value in the order of 10⁻¹⁰ cm²/sec for the removal of Reactive Red 2 by a mixture of two adsorbents and these authors suggested that the adsorption process was governed by pore diffusion even though it could not be ascertained that pore diffusion was the only rate determining step.

Since both external Mass transfer and intra particle diffusion constants varied with initial Reactive Blue 2 concentration indicating the occurrence of both surface adsorption and intra particle diffusion, the sorption data were further analyzed by the kinetic expression given by Boyd et al³⁰,

$$F = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[\frac{-Dit\pi^2 n^2}{r^2} \right] \quad (15)$$

$$F = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[-n^2 \beta_1 \right] \quad (16)$$

Where F is the fractional attainment of equilibrium at time t and is obtained by using following equation and n is the Freundlich constant of the adsorbate.

$$F = \frac{q_t}{q_e}$$

Where q_t and q_e are the amounts adsorbed at time t and at equilibrium respectively.

On the basis of F values, corresponding values of B_t were obtained from Reichenberg's table³¹ and the linearity test was carried out by plotting B_t with respect to time for both the solutions at different time intervals and at 30 °C, 45 °C and 60 °C. The linearity test of B_t versus time plot drawn for different concentrations is employed to distinguish between film diffusion and particle diffusion. From the slope of the straight line obtained from time versus B_t graph, B value (time constant) was calculated. The values of effective diffusion coefficient (D_i)

were calculated at different temperatures using the following equation.

$$B = \pi^2 D_i / r^2 \quad (17)$$

here r is the radius of adsorbent particle. The D_i values are given in the Table 5.

The plot of $1/T$ versus $\log D_i$ was found linear with negative slope indicating thereby the increase in the mobility of the ions. This is due the fact that with the rise in temperature the mobility of the ion increases, which consequently decreases the retarding force acting on the diffusing ions.

The values of energy of activation E_a , entropy of activation $\Delta S^\ddagger$ and pre exponential constant D_0 were calculated using the following equations.

$$D_i = D_0 \exp[-E_a / RT] \quad (18)$$

$$D_0 = (2.72d^2 kT / h) \exp[\Delta S^\ddagger / R] \quad (19)$$

Where d is the average distance between the successive exchange sites and is taken as $5A^\circ$, R , h and k are the gas, plank and Boltzmann constants respectively. The values of E_a , D_i , D_0 , $\Delta S^\ddagger$ and other parameters are given in the Table 5. The negative values of $\Delta S^\ddagger$ reflect that no significant change occurs in the internal structure of chosen adsorbent using the adsorption process.

Thermodynamics Parameters

ΔH and ΔS values were obtained from the slope and intercept of Vant Hoff plot ($1/T$ vs $\ln K_c$). A batch adsorption study were carried out with Reactive Blue 2 solution at $pH \approx 6.5$ and by varying the temperature (303K, 318K and 333K). The initial concentration of Reactive Blue 2 solution used was maintained to be 20 mg/L with 50mg of the absorbent Table 6. Gives the value of ΔG , ΔS and ΔH for the adsorption of Reactive Blue 2. The negative values of free energy change (ΔG) indicate the feasibility and spontaneous nature of the adsorption of Reactive Blue 2 species. The negative ΔH values of the process suggest the exothermic nature of the absorption of Reactive Blue 2 on to activated *Jatropha Curcas* stem waste carbon. The negative value of ΔS is due to the increased randomness during the adsorption of Reactive Blue 2.

Conclusion

In the present study adsorption of Reactive Blue 2 on activated *Jatropha Curcas* stem waste carbon has been investigated. The data obtained through this work supports that the *Jatropha Curcas* stem waste carbon is an effective low cost adsorbent for the removal of Reactive Blue 2 from aqueous solution. The adsorption of Reactive Blue 2 is dependent on the initial concentration and agitation time. Equilibrium of Reactive Blue 2 adsorption reaches at 160 min.

The pseudo first and second order equations provide a best fit description for the sorption of Reactive Blue 2 on to *Jatropha Curcas* stem waste related to Elovich model, but the pseudo second order correlation coefficient has better correlation value than pseudo first order equation, pseudo second order equation is consider to be the most appropriate due to high correlation coefficient when compared to pseudo first order equation.

Langmuir and Freundlich adsorption isotherm correlate the equilibrium adsorption data. The adsorption of Reactive Blue 2 on to activated *Jatropha Curcas* stem waste carbon is an exothermic reaction based on enthalpy change values.

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