

ADSORPTION STUDIES OF BASIC RED 29 BY A NON-CONVENTIONAL ACTIVATED CARBON PREPARED FROM EUPHORBIA ANTIQUORUM L

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ABSTRACT: In this investigation, the mechanism of the adsorption of Basic Red 29 from aqueous solution using an activated carbon prepared from *Euphorbia antiquorum* L wood was studied. The adsorption reaches the equilibrium at 90 minutes of contact time. The kinetic data were fitted to the pseudo first-order, pseudosecond-order, Elovich and intraparticle diffusion models. The pseudo second-order rate constant decreases from 2.364×10^{-3} to 3.744×10^{-4} (g/mg.min) with increase in initial dye concentration from 25 mg/L to 100 mg/L. Experimental isotherm data collected at different temperatures were fitted in Langmuir, Freundlich, Tempkin and Dubinin-Raduskevich adsorption isotherm models. Based on the mean free energy, the adsorption of BR29 on to EAAC is physisorption in nature. Thermodynamic parameters like ΔH° , ΔS° and ΔG° were measured based on van't Hoff's plot. Maximum desorption of 43.33 % observed at a pH range of 2 to 4.

Key words : Adsorption, Activated carbon, Basic Red 29, Dye, Kinetics, Isotherm.

1.0 INTRODUCTION

Discharge of dyeing industrial effluents on the land and water bodies poses a serious threat to the environment due to its high toxicity and non-biodegradable nature. Recently many technologies like electrochemical coagulation, reverse osmosis, nano filtration, adsorption using activated materials etc., are used for the removal of dye from waste water. Adsorption has been proposed as a feasible and economical process for the treatment dyeing industry effluent. In recent past, many researchers have proved that activated carbon prepared from agricultural wastes and useless plant materials can remove substantial amount of dyes from the effluents.

Exploration of good low cost and non-conventional adsorbent may contribute to the sustainability of the environment and offer promising benefits for the commercial purpose in future. The costs of the activated carbon prepared from biomaterials are negligible when compared to the cost of commercial activated carbon. The biological products are renewable sources of raw materials for the production of activated carbon.

Some of the materials which are used for the preparation of activated carbon in the recent past are, saw dust [1], pinus pinaster bark [2], eucalyptus bark [3],

pistachio shells[4], agricultural wastes[5], oil palm waste[6], easy growing wood species[7], tamarind kernel powder[8], palm shell[9], tropical wood [10], babool wood [11], etc., All of these carbons were successfully applied for the wastewater purification.

The two different processes followed for the preparation of activated carbon are physical and chemical activation. Physical activation involves carbonization of precursor followed by activation of the resulting char in presence of activating agents such as CO₂ or steam. On the other hand, chemical activation involves the carbonization of precursor in presence of chemical agents. Chemical activation has more advantages over physical activation with respect to higher yield, more surface area, better development of porous structure and oxygenated surface complexes in carbon.

The purpose of the present work is to investigate the adsorption of Basic Red 29 onto an activated carbon prepared from *Euphorbia antiquorum* L wood by H₃PO₄ impregnation followed by activation. About the precursor plant, it is wide spread throughout peninsular India, it can be found growing up to an altitude of 800 m. One of the largest armed tree in Euphorbias, with an average height of 5 - 7 m., it has been known to attain gigantic proportions if left undisturbed. The odour of its latex is

pungent and lingering. The most important point about this plant is it does not have any economical importance.

2.0 EXPERIMENTAL

2.1 Adsorbent

Euphorbia antiquorum L wood used as precursor for the preparation of activated carbon. The wood cut into pieces of 2 cm to 3 cm size, dried in sunlight for 10 days. The dried material soaked in a boiling solution of 10 % H_3PO_4 for one hour and kept at room temperature for 24 hours. After 24 hours the wood material separated, air dried and carbonised in muffle furnace at 400°C. The carbonised material was powdered and activated in a muffle furnace at 800°C for a period of 10 minutes. Then the material was washed with plenty of water to remove residual acid, dried, sieved to a desired particle size and stored in a tight lid container for further adsorption studies.

2.2 Adsorbate

All the chemicals used are reagent grade. A cationic dye (Basic Red 29) having molecular formula, $C_{19}H_{17}N_4SCl$, (F. Wt: 368.89) with CI No. 11460, (E. Merck, India) was chosen as the adsorbate. A stock solution of 1000 mg per litre of the dye was prepared using double distilled water and used for the preparation of adsorbate solutions by appropriate dilution as required.

2.3 Character studies

Physico-chemical characteristics of the activated carbon samples were studied as per the standard testing methods[12,13]. The N_2 adsorption-desorption isotherms of activated carbon were measured at 77K using N_2 gas sorption analyzer (Nova 1000, Quanta Chrome Corporation) in order to determine the surface area using the BET equation.

2.4 Adsorption Studies

The adsorption experiments were carried out in 250 ml tight lid reagent bottle (Borosil-R) by agitating 100 mg of adsorbent with a 200 ml of the aqueous dye solution. The contents of the flasks were agitated by placing them in a temperature controlled orbital shaker. The mixture withdrawn at specified interval then centrifuged using electrical centrifuge (Universal make) at 5000 rpm for 10 minutes and unadsorbed supernatant liquid analyzed for the residual dye concentration using Elico make Bio-UV visible spectrometer (BL-198) at 510 nm. The pH of the adsorptive solution was adjusted using 0.1 N NaOH and 0.1 N HCl [14]. All the experiments conducted in duplicate and mean of the two values are taken for calculation. Maximum deviation is 4 %. In order to simplify the discussion, hereafter Basic Red 29 will be designated as BR29 and the *Euphorbia antiquorum* L activated carbon will be designated as EAAC.

2.5 Desorption Studies

Desorption studies help to elucidate the nature of adsorption and recycling of the spent adsorbent. Desorption studies as a function of pH were conducted to analyze the possibility of reuse the adsorbent for further adsorption and to make the process more economical. After adsorption experiments the dye loaded carbon washed gently with double distilled water to remove any un-adsorbed dye if present. Desorption studies were conducted using several such carbon samples. 500 mg of the dye loaded carbon agitated above the equilibration time with 50 ml of double distilled water of various pH.

3 RESULTS AND DISCUSSION

3.1 Adsorbent Characteristics

The physico-chemical characteristics of all the nine varieties of the prepared activated carbon were published in our earlier paper[15]. In this part of work, carbon prepared by H_3PO_4 activation method was selected to analyse the adsorption characteristics of Basic Red 29 dye. Some of the important properties are given in table1.

3.2 Effect of initial dye concentration and contact time

The effect of initial dye concentration and contact time for the removal of BR29 by EAAC is shown in the fig. 1. For this study 200 ml of 25 to 100 mg/L of dye solution agitated with 100 mg of adsorbent. Rapid uptake of the dye noticed during the initial 30 minutes of contact time and reaches the equilibrium around 90 minutes for all the ranges of concentrations studied. The uptake of dye increased from 47.62 mg/g to 139.13 mg/g while increasing the initial dye concentration from 25 mg/L to 100 mg/L. The maximum percentage of dye removal at equilibrium time was 95.24 %, this may be due to the absence of other solute materials.

Availability of dye molecules near adsorbent also increased while increasing the concentration, which results high uptake of dye at higher concentration. Similar results were reported for the adsorption of some cationic dyes like Methylene blue on to Sago waste and adsorption of Methyl violet by Bagasse [16]. The adsorption curves are single, smooth and leading to a saturation, suggesting the mono layer coverage of BR29 on to EAAC. Based on this result, there is no change in the sorption capacity after 90 minutes and there fore 120 minutes is fixed as the optimum contact time for equilibrium studies.

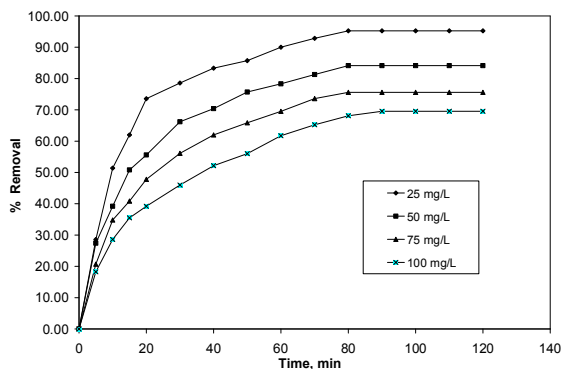


Fig. 1 Effect of agitation time on the adsorption BR29 on to EAAC at 30°C (pH, 8.62; adsorbent dosage, 100 mg; adsorbent size, 300 to 850 μm)

3.3 Effect of pH

The effect of pH for the adsorption of BR29 on to EAAC over a pH range of 2 to 11 is represented in fig. 2. The percentage dye adsorption increases with increase in pH from 2 to 8 and remains constant there after. When the pH is increased, the number of negatively charged sites increases. The electrostatic attraction between the negative surface and the cationic dye molecule increases with pH and reaches a saturation at a pH of 8 [17]. Similar trend was reported for the adsorption of BR41 by silkworm pupa [18].

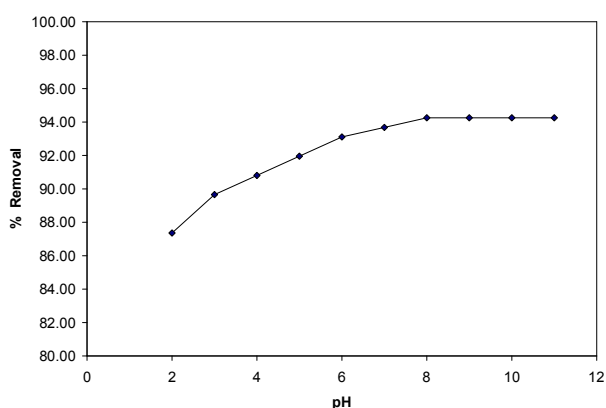


Fig. 2 Influence of pH on the adsorption BR29 on to EAAC at 30°C (initial concentration, 50 mg/L; time, 180 min)

3.4 Effect of temperature on dye removal

The percentage of BR29 sorption by EAAC increases from 84.13 to 92.06 % while increasing the temperature from 30°C to 50°C. The increases in uptake with temperature indicates that the sorption of BR29 by EAAC is endothermic in nature.

3.5 Kinetics of Adsorption

Many kinetic models have been proposed to elucidate the mechanism of solute adsorption. The rate and mechanism of adsorption is controlled by various

factors like physical and/or chemical properties of adsorbent, ambient temperature, solution pH and nature of adsorbate. These kinetic models are useful for the design and optimization of effluent-treatment process. In order to investigate the mechanism of BR29 adsorption by EAAC the following four kinetic models were considered.

3.5.1 Pseudo first-order kinetic model

The pseudo first-order kinetic model was proposed by Lagergren [19].

The integrated linear form of the model is

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \quad (1)$$

Where,

q_e is the amount of dye adsorbed at equilibrium (mg/g),

q_t is the amount of dye adsorbed at time t (mg/g),

k_1 is the first-order rate constant (min^{-1}) and t is time (min).

Hence, a linear trace is expected between the two parameters, $\log(q_e - q_t)$ and t , provided the adsorption follows first order kinetics. The values of k_1 and q_e can be determined from the slope and intercept.

The results of pseudo first-order plot for the adsorption of BR29 by EAAC are given in table 2 (figure not shown). The pseudo first-order rate constant ranged between 0.04652 to 0.03547 min^{-1} . The correlation coefficient r^2 found to range from 0.968 to 0.9906. The calculated and experimental q_e values shows a reasonable correlation in the case pseudo first-order kinetics. Even though $q_{e,\text{cal}}$ (calculated value) and $q_{e,\text{exp}}$ (experimental value) are closer, the r^2 values suggests that the adsorption data fitted poor to pseudo first-order kinetics. Hence, the adsorption BR29 onto EAAC does not follow the pseudo first-order rate expression.

3.5.2 Pseudo second-order kinetics

The adsorption may also be described by pseudo second-order kinetic model [20] if the adsorption does not follows the first order kinetics. The linearized form of the pseudo second-order model is

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

Where,

k_2 is the second-order rate constant (g/mg min)

the initial adsorption rate, h (mg/g min), as $t \rightarrow 0$ can be defined as

$$h = k_2 q_e^2 \quad (3)$$

and q_e is the equilibrium adsorption capacity (mg/g).

A plot of t/q_t and t should give a linear relationship if the adsorption follows second order. q_e and k_2 can be calculated from the slope and intercept of the plot.

Fig. 3 shows the pseudo second-order plot for the adsorption of BR29 by EAAC at various initial dye

concentrations and the results are given in table 2. The equilibrium sorption capacity, q_e and initial sorption rate, h increases while increasing the initial dye concentration. The pseudo second-order rate constant decreases from 2.364×10^{-3} to 3.744×10^{-4} (g/mg min) with increases in initial dye concentration. The correlation coefficient r^2 ranges from 0.9712 to 0.9925, which is higher than pseudo first-order values. From the results it can be suggested that pseudo second-order describes the adsorption of BR29 by EAAC much better than pseudo first-order model.

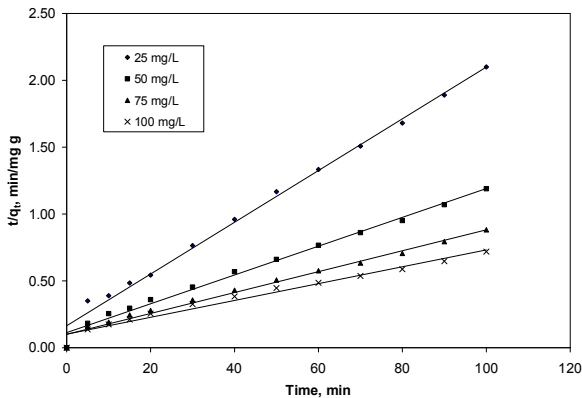


Fig. 3 Pseudo second order plot for the adsorption BR29 on to EAAC at 30°C (pH, 8.62; adsorbent dosage, 100 mg; adsorbent size, 300 to 850 μm)

3.5.3 Elovich model

The Elovich equation is mainly applicable for chemisorption kinetics. The equation is often valid for systems in which the adsorbing surface is heterogeneous [21]. The Elovich model is generally expressed as

$$\frac{dq_t}{dt} = \alpha e^{-\beta q_t} \tag{4}$$

Integrating this equation for the boundary conditions, gives

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \tag{5}$$

Where,

α is the initial adsorption rate (mg/g min) and β is related to the extent of surface coverage and the activation energy for chemisorption (g/mg).

A plot of q_t vs $\ln t$ gives a linear trace with a slope of $(1/\beta)$ and an intercept of $1/\beta \ln(\alpha\beta)$. The results of Elovich plot for the adsorption of BR29 by EAAC at various initial dye concentrations are given in table 2 (figure not shown). The plot is linear with good correlation coefficient (r^2 0.9818 to 0.9914). The initial adsorption rate, α , increases from 11.065 to 23.275 mg/g min while increasing the initial dye concentration from 25 to 100 mg/L.

3.5.4 Intra particle diffusion model

In the batch mode adsorption process, initial adsorption occurs on the surface of the adsorbent. In addition, there is a possibility of the adsorbate to diffuse into the interior pores of the adsorbent. Weber and morris [22] suggested the following kinetic model to investigate the adsorption is intra-particle diffusion or not. According to this theory

$$q_t = k_d \cdot t^{1/2} \tag{6}$$

Where, k_d is the intraparticle diffusion rate constant and is calculated by plotting q_t vs $t^{1/2}$ (fig. 4) and the results are given in table 2. The linear portion of the plot for wide range of contact time between adsorbent and adsorbate does not pass through the origin. This deviation from the origin or near saturation may be due to the variation of mass transfer in the initial and final stages of adsorption [23]. Such a deviation from the origin indicates that pore diffusion is the only controlling step and not the film diffusion. The initial pore diffusion due to external mass transfer ($r^2 = 0.9859$ to 0.9972) followed by the intra particle diffusion (r^2 is in the range 0.9748 of to 0.9986). The high correlation coefficient in the first region conforms that pore diffusion play a major role for the adsorption BR29 by EAAC.

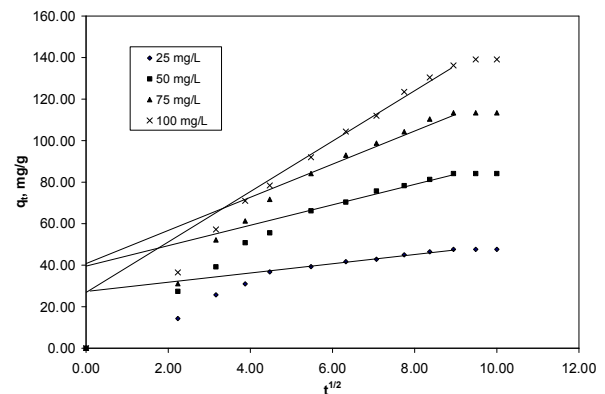


Fig. 4 Intra particle diffusion plot for the adsorption BR29 on to EAAC at 30°C (pH, 8.62; adsorbent dosage, 100 mg; adsorbent size, 300 to 850 μm)

3.6 Adsorption isotherm

The equilibrium existence of adsorbate between the liquid and solid phase is well described by adsorption isotherms. Experimental isotherm data collected at different temperatures were fitted in Langmuir, Freundlich, Tempkin and Dubinin-Raduskevich adsorption isotherm models.

3.6.1 Langmuir model

The Langmuir model was originally developed to describe the adsorption of gas on to solid surface. It suggests the formation of monolayer adsorption and also the surface is energetically homogeneous. The Langmuir isotherm can be expressed as [24].

$$q_e = \frac{Q_0 \cdot b_L \cdot C_e}{(1 + b_L \cdot C_e)} \tag{7}$$

Linear form of the rearranged Langmuir model is

$$\frac{C_e}{q_e} = \frac{1}{Q_0 \cdot b_L} + \frac{C_e}{Q_0} \quad (8)$$

Where,

Q_0 is a constant related to adsorption capacity (mg/g) and b_L is Langmuir constant related to energy of adsorption (L/mg). The constants Q_0 and b_L can be calculated from the slope and intercept of the plot of C_e/q_e vs C_e .

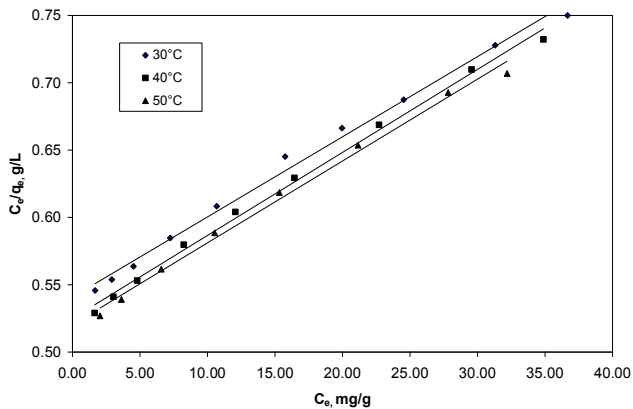


Fig. 5 Langmuir isotherm for the adsorption BR29 on to EAAC at various temperatures (pH, 8.62; agitation time, 180 min; adsorbent dosage, 100 mg; adsorbent size, 300 to 850 μ m)

The Langmuir plot of C_e/q_e vs C_e at 30, 40 and 50°C is shown in fig. 5. The results calculated from the plot are given in table 3. The Langmuir adsorption capacity varies from 166.67 mg/g to 161.29 mg/g with the range of temperatures studied. The value is comparable with the values reported for the adsorption of methylene blue onto rice hush carbon [25]. The essential characteristics of Langmuir isotherm can be expressed by dimensionless separation factor, R_L [26].

$$R_L = 1 / (1 + b_L \cdot C_0) \quad (9)$$

The value of separation factor R_L indicates the nature of the adsorption process as given below

$R_L > 1$ Unfavourable

$R_L = 1$ Linear

$0 < R_L < 1$ Favourable

$R_L = 0$ Irreversible

Where b_L is the Langmuir constant and C_0 is the initial concentration (mg/L). The R_L value ranges between 0.5546 and 0.5906 for the range of temperatures studied. The R_L value between 0 and 1 indicate favourable adsorption.

3.6.2 Freundlich model

It is a most popular model for a single solute system, based on the distribution of solute between the solid phase and aqueous phase at equilibrium [27]. The Freundlich equation is expressed as

$$q_e = k_f \cdot C_e^{1/n} \quad (10)$$

Where, k_f is the measure of adsorption capacity and n is the adsorption intensity

Linear form of Freundlich equation is

$$\log q_e = \log k_f + \frac{1}{n} \log C_e \quad (11)$$

A plot of $\log q_e$ vs $\log C_e$ gives a linear trace with a slope of $1/n$ and intercept of $\log k_f$ and the results are given in table 3.

When $1/n$ is >1.0 , the change in adsorbed dye concentration is greater than the change in the dye concentration in solution.

The Freundlich model is suitable for use with heterogeneous surface but can describe the adsorption data over a restricted range only. It is often found that the Freundlich equation is fitted well to data at higher and intermediate concentrations, since the Freundlich equation does not approach Henry's Law of ideal dilute solutions [28]. The Freundlich constant, k_f increases from 39.084 to 66.15 ($\text{mg}^{1-1/n} \text{L}^{1/n} \text{g}^{-1}$) while increasing the temperature from 30°C to 50°C. It has been shown that n values between 1 and 10 represent beneficial adsorption. The value of n is greater than 1.0 indicating the adsorption AB92 on to EAAC is favourable. Langmuir model is more appropriate to explain the nature of adsorption with correlation coefficient of 0.9935 to 0.996 rather Freundlich model shows poor fit ($r^2 = 0.9809$ to 0.9912).

3.6.3 Tempkin isotherm

The Tempkin isotherm assumes that the fall in the heat of adsorption is linear rather than logarithmic as stated in Freundlich expression [29]. The heat of sorption of all the molecules in the layer would decrease linearly with coverage due to sorbate/sorbent interactions. The Tempkin isotherm is applied in the following form

$$q_e = \left(\frac{RT}{b_T} \right) \ln(a_T \cdot C_e) \quad (12)$$

The linear form of Tempkin equation is

$$q_e = \frac{RT}{b_T} \ln a_T + \frac{RT}{b_T} \ln C_e \quad (13)$$

Where,

b_T is the Tempkin constant related to heat of sorption (J/mg) and

a_T the equilibrium binding constant corresponding to the maximum binding energy (L/g)

The Tempkin constants a_T and b_T are calculated from the slopes and intercepts of q_e vs $\ln C_e$ are given in table 3. Out of four isotherm models studied for this adsorbent-adsorbate system, Tempkin model shows best fit with a correlation coefficient of 0.9926 to 0.9977.

3.6.4 Dubinin-Radushkevich isotherm

The isotherm proposed by Dubinin [30] has the following form

$$q_e = q_D \cdot e^{-B\varepsilon^2} \quad (14)$$

Linear form of Dubinin-Radushkevich isotherm is

$$\ln q_e = \ln q_D - B\varepsilon^2 \quad (15)$$

Where,

q_D is the theoretical saturation capacity (mg/g)

B is a constant related to the mean free energy of adsorption per mole of the adsorbate (mol^2/J^2) and

ε is polanyi potential which is related to the equilibrium as follows;

$$\varepsilon = RT \ln(1+1/C_e) \quad (16)$$

A plot of $\ln q_e$ vs ε^2 gives a linear trace and the constants q_D and B calculated from the slope and intercept respectively. The mean free energy of adsorption E calculated from B using the following equation

$$E = 1/(2B)^{1/2} \quad (17)$$

Based on this energy of activation we can predict whether an adsorption is physisorption or chemisorption. If the energy of activation is <8 kJ/mol, the adsorption is physisorption and if the energy of activation is 8–16 kJ/mol, the adsorption is chemisorption in nature [31]. Based on the mean free energy calculated from the constant β (table 3), we can predict that the adsorption of BR29 on to EAAC is physisorption in nature.

3.7 Thermodynamics of adsorption

Thermodynamic parameters like ΔH° , ΔS° and ΔG° were measured based on van't Hoff's plot.

$$\ln k_L = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{R} \frac{1}{T} \quad (18)$$

Where,

k_L is the Langmuir equilibrium constant,
 ΔH° and ΔS° are the standard enthalpy and entropy changes of adsorption respectively and

The values of ΔH° and ΔS° are calculated from the slopes and intercepts of the linear plot of $\ln k_L$ vs $1/T$. The free energy of specific adsorption ΔG° (kJ/mol) is calculated from the following expression

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (19)$$

The thermodynamical parameters calculated from Eyring's plot are given in table 4. Negative standard

free energy of adsorption indicates that the adsorption process is favourable and spontaneous in nature.

The endothermic nature of adsorption is confirmed by the positive ΔH° value. The bonding between BR29 and EAAC surface is very weak, since ΔH° value is found to be $1.589 \text{ kJ mol}^{-1}$. Positive values of ΔS° suggested good affinity of the dye towards the adsorbent and the adsorption is spontaneous in nature [32].

3.8 Desorption Studies

A significant amount of dye desorbed from the dye loaded carbon, since the adsorption process is mainly physical in nature. Maximum desorption of 23.33 % observed at a pH range of 2 to 4. High percentage of desorption at lower pH is due to the presence of more amount of competitive H^+ ions. Desorption decreases with increasing the pH. The high percentage of desorption at lower pH will be helpful for recycling the spent adsorbent.

4.0 CONCLUSION

Activated carbon for the adsorption of dye from its aqueous solution can be conveniently and economically prepared from Euphorbia antiquorum L wood. The physico-chemical characteristic of the prepared activated carbon is comparable with the commercial activated carbon. The uptake of dye increased from 47.62 mg/g to 139.13 mg/g while increasing the initial dye concentration from 25 mg/L to 100 mg/L. The adsorption of BR29 increases with temperature indicates that the sorption process is endothermic in nature. The pseudo second-order kinetic model describes the adsorption much better than pseudo first-order model. Intra particle diffusion model proves that pore diffusion play a major role for the adsorption BR29 by EAAC. The Langmuir adsorption capacity varies from 166.67 mg/g to 161.29 mg/g with the range of temperatures studied. Langmuir model is more appropriate to explain the nature of adsorption with high correlation coefficient. Tempkin model shows best fit with a correlation coefficient of 0.9926 to 0.9977. The positive ΔH° value suggests that the adsorption is endothermic in nature.

Table 1: Physico-chemical characteristics of EAAC

S.No	Properties	Values
1	pH	6.90
2	Moisture content, %	7.56
3	Bulk density, g/mL	0.48
4	Porosity, %	55.32
5	pH _{ZPC}	6.82
6	Surface area (BET), m ² /g	918
7	Fixed Carbon, %	57.94

Table 2: Calculated kinetic parameters for the adsorption of BR29 onto EAAC

Concentration (mg/L)	25	50	75	100
First order kinetics				
k_1 (min ⁻¹)	0.0465	0.0444	0.0451	0.0355
$q_{e,cal}$ (mg/g)	36.78	72.79	108.44	128.17
$q_{e,exp.}$ (mg/g)	47.62	84.13	113.41	139.13
r^2	0.9680	0.9906	0.9687	0.9794
Second order kinetics				
$k_2 \times 10^{-4}$ (g/mg min)	23.64	10.31	6.078	3.741
h	6.2814	8.8339	9.9900	9.4251
$q_{e,cal}$ (mg/g)	51.44	92.59	128.21	158.73
r^2	0.9925	0.9892	0.9840	0.9718
Elovich model				
α (mg/g min)	11.065	17.334	16.447	23.275
β (g/mg)	0.0883	0.0508	0.0376	0.0325
r^2	0.9815	0.9954	0.9894	0.9813
Intra particle diffusion model				
k_{id} (mg/g min)	2.741	6.825	10.539	13.345
r^2	0.9813	0.9768	0.9847	0.9986

Table 3: Results of various isotherm plots for the adsorption of BR29 on to EAAC

Temperature °C	30	40	50
Langmuir			
Q_0 (mg/g)	166.67	161.29	163.93
b (L/mg)	0.0111	0.0119	0.0117
k_L	1.849	1.905	1.922
r^2	0.9935	0.996	0.9938
Freundlich			
n	2.6767	3.2808	4.1051
k_f (mg ^{1-1/n} L ^{1/n} g ⁻¹)	39.084	52.541	66.145
r^2	0.9867	0.9809	0.9912
Tempkin			
b_T (J/mg)	72.068	86.751	98.769
a_T (L/g)	3.067	24.322	117.05
r^2	0.9958	0.9977	0.9926
Dubinin-Raduskevich			
q_D (mg/g)	1.00	1.00	1.00
$B \times 10^{-7}$ (mol ² /J ²)	2.0	1.0	1.0
E (kJ/mol)	2.236	3.162	3.162
r^2	0.9330	0.9357	0.8958

Table 4: Thermodynamical parameters for the adsorption BR29 onto EAAC

Temperature, °C	ΔH° , kJ/mol	ΔS° , J/K/mol	ΔG° , kJ/mol
30			- 1.556
40	1.5884	10.3784	- 1.660
50			- 1.763

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