Dye Sorption onto Activated Carbons Prepared from Balsamodendron caudatum Wood Waste-A Comparative Study

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Abstract: Balsamodendron caudatum wood waste was employed for the removal of Rhodamine B from aqueous solution under different experimental conditions was investigated. Characterisation of activated carbon prepared using Balsamodendron caudatum wood waste by two different process (BAC1 and BAC2) were employed. The influences of initial Rhodamine B concentration (20, 40 and 60 mg/L), and temperatures (30°, 45° and 60°C) and pH have been reported. A comparison of kinetic models applied to adsorption of Rhodamine B on to each adsorbent was evaluated for pseudo first–order, pseudo second-order and Elovich models respectively. Results show that the pseudo first order kinetic model was found to correlate the experimental data well. The results show that Rhodamine B interacts strongly with the prepared activated carbons and hence the adsorbents are good for the removal of Rhodamine B from aqueous solution.

Keywords: Adsorption Rhodamine B, Adsorption kinetics, aqueous solution.

Introduction
Textile effluents are in general tough to treat because of their high organic content, tough pH conditions and due to the presence of a variety of classes of dyes. The most commonly used dyes in the textile arena for dyeing are the azo dyes owing to its cheaper cost, contributes to about 50-65% of the total colors used for dyeing purpose \[1,2\]. Due to their poor exhaustion properties (10-30%) of the dye components end up in the effluent \[3\]. The major drawback of the usage of azo dye is that they are recalcitrant in nature and when ingested could prove fatal to the living forms \[4\]. Till now these effluents were treated through physical and chemical means but they have many disadvantages like their lack of implementation which has been largely due to high cost, low efficiency and generation of toxic by-products \[5\]. Among industrial sectors, textile industries are rated as high polluters, taking into consideration the volume of discharge and effluent composition. It has been estimated that 10–15% of the dye is lost in the dye effluent \[6\]. The discharge of dyes in the environment is a matter of concern for both toxicological and esthetical reasons, causing serious water pollution problems to aquatic life due to the reduced light penetration \[7,9\]. The presence of these dyes in water, even at very low concentrations (less than 1 ppm for some dyes), is highly visible and undesirable\[9,10\]. Adsorption is one of the most widely used methods for wastewater treatment. Adsorption is a surface phenomenon, where the solid surface in contact with a solution has a tendency to accumulate a surface layer of soluble molecules because of the imbalance of surface forces \[11\]. An attempt was made in this work to prepare two types of activated carbons from Balsamodendron caudatum wood waste material (BAC1 and BAC2) with varying pore structure and surface area using phosphoric acid\[12, 13\], sulfuric acid\[14,15\] processes, which are used to remove Rhodamine B from aqueous solution using temperature, concentration and pH as parameters.

Material and Methods
Adsorbent: Balsamodendron caudatum wood waste was obtained from various regions of Erode and Tirupur Districts, TamilNadu, India. The study of Balsamodendron caudatum wood waste material is used as adsorbent is expected to be economical, environmentally safe and it has practical importance.

To develop adsorbents, the material was first ground and washed with doubly distilled water and then...
dried. The dried material thus obtained was treated with hydrogen peroxide (30%W/V) at room temperature for about 24 hrs to oxidize the adhering organic matter. The resulting material was thoroughly washed with doubly distilled water and then subjected to the temperature of 120°C for the moisture removal.

One portion of the above material was soaked well with H₂SO₄ solution for a period of 24 hours. At the end of 24 hrs the excess of H₂SO₄ solution were decanted off and air-dried. Then the materials were placed in the muffle furnace carbonized at 120-130°C. The dried materials were powdered and activated in a muffle furnace kept at 800°C for a period of 60 minutes. After activation, the carbon of obtained were washed sufficiently with large volume of water to remove free acid. Then the obtained material was washed with plenty of water to remove excess of acid, dried then to desired particle size. Another portion of the material was activated with activating agents H₃PO₄ as per the H₂SO₄ activation process described above, and they sieved to desired particle size. Final products obtained in each case were stored separately in a vacuum desicator until used. The resulting carbons named as (BAC1and BAC2).

The N₂ adsorption-desorption isotherms of activated carbons were measured at 77K using a gas sorption analyzer (NOVA 1000, Quanta Chrome corporation) in order to determine the surface areas and the total pore volumes. The surface areas were calculated using the BET equation.

**Batch adsorption studies**

All reagents used were of AR grade (E merk). 50mL of Rhodamine B solution of known concentration (C₀) at pH 6.5 was taken in a 100ml screw-cap conical flask with a required amount of adsorbent and was agitated at a speed of 200 rpm in a thermostatic shaker bath at 27° C for a specified period of time. Then the solution was filtered through a 0.45 µm membrane filter.

**Determination of Rhodamine B**

Rhodamine B was estimated spectrophotometrically. A calibration graph for 5-50mg of Rhodamine B was prepared by the above procedure and concentration in the sample aliquot was established by referring to the calibration graph.

\[ q_t = \frac{C_0 - C_t}{m_s} \times V \]  

\[ (1) \]

The amount of Rhodamine B adsorbed in mg/L at time t was computed by using the following equation.

where, C₀ and C₁ are the Basic dye concentration in mg/L initially and a given time t, respectively, V is the volume of the Basic dye solutions in mL and ms is the weight of the activated carbon.

The percentage of removed Rhodamine B ions (R %) in solution was calculated using eqn. (2)

\[ \% \text{ Removed} = \frac{C_0 - C_t}{C_0} \times 100 \]  

\[ (2) \]

The initial concentration of Rhodamine B, pH and temperature was investigated by varying any one parameters and keeping the other parameters constant.

**Adsorption dynamics**

The study of adsorption dynamics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at the solid-solution interface. The kinetics of Rhodamine B adsorption on the activated carbons were analyzed using pseudo first order [16], pseudo second order [17] kinetic models and Elovich equation [18]. The conformity between experimental data and the model predicted values was expressed by the correlation coefficients \( r^2 \) values closer or equal to 1. A relatively high \( r^2 \) value indicates that the model successfully describes the kinetics of Rhodamine B adsorption.

**The pseudo first – order equation**

The pseudo first-order equation [16] is generally expressed as follows.

\[ \frac{dq_t}{dt} = k_1(q_e - q_t) \]  

\[ (3) \]

where, qₑ and qₜ are the adsorption capacity at equilibrium and at time t, respectively (mg g⁻¹), k₁ is the rate constant of pseudo first-order adsorption (l min⁻¹).

After integration and applying boundary conditions t=0 to t = t and qₜ= 0 to qₑ = qₑ, the integration form of equation (3) becomes.

\[ \log(q_e - q_t) = \frac{\log(q_e) - k_1 \times t}{2.303} \]  

\[ (4) \]

The value of \( \log(q_e - q_t) \) were linearly correlated with t. The plot of log (qₑ - qₜ) Vs t should give a linear relation ship from which k₁ and qₑ can be determined from the slope and intercept of the plot, respectively.

**The pseudo second – order equation.**

\[ \frac{dq_t}{dt} = k_2(q_e - q_t)^2 \]  

\[ (5) \]

The pseudo second-order adsorption kinetic rate equation is expressed as [17]

\[ \frac{1}{q_e - q_t} = \frac{1}{q_e + k_2t} \]  

\[ (6) \]
where, \( k_2 \) is the rate constant of pseudo second order adsorption (g mg\(^{-1}\) min\(^{-1}\)). For the boundary conditions \( t = 0 \) to \( t = t \) and \( q_i = 0 \) to \( q_t = q_e \), the integrated form of equation (5) becomes:

\[
\frac{t}{q_t} = \frac{1}{k_2q_e^2} + \frac{1}{q_e}(t)
\]

(7)

Which is the integrated rate law for pseudo second – order reaction. Equation (6) can be rearranged to obtain equation (7), which has a linear form.

\[
h = k_2q_e^2
\]

(8)

If the initial adsorption rate \( h \) (mg g\(^{-1}\) min\(^{-1}\)) is

Then Equations. (7) And (8) become:

\[
\left( \frac{t}{q_t} \right) = \frac{1}{h} + \frac{1}{q_e}(t)
\]

(9)

The plot of \((t/q_t)\) and \( t \) of equation (7) should give a linear relationship from which \( q_e \) and \( k_2 \) can be determined form the slope and intercept of the plot, respectively.

The Elovich equation

\[
\frac{dq_t}{dt} = \alpha \exp\left(-\beta q_t\right)
\]

(10)

The Elovich model equation is generally expressed\(^{[18]}\) as

where, \( \alpha \) is the initial adsorption rate (mg g\(^{-1}\) min\(^{-1}\)), \( \beta \) is the adsorption constant (g mg\(^{-1}\)) during any one experiment.

**Results and Discussion**

Physico-chemical characterizations of the adsorbents were presented in Table 1.

**Optimum pH:** The adsorption behavior of the dye on both the adsorbents was studied over a wide pH range of 2.0-10.0. Figure 1 depicts that the pH significantly affects the extent of adsorption of dye over both adsorbents and a reduction the amount adsorbed with increasing pH was observed in both cases. Figure 1 also specifies that maximum uptake of the Rhodamine B is observed at pH 6.5 on BAC1 as well as BAC2. The percentage of amount of dye adsorbed then increases up to pH 6.5 for BAC1 and pH 6.4 for BAC2. After this pH it remains almost constant in both cases. As the surface charge density decreases with an increase in the solution pH, the electrostatic repulsion between the positively charged dye and the surfaces of adsorbent is reduced, this causes more adsorption\(^{[19]}\). At pH above pH\(_{zc}\), the surface of adsorbent may acquire a negative charge leading to an increased cationic dye adsorption, due to electrostatic attraction.

**Effect of concentration**

The batch adsorption experiments were carried out by using three different concentrations of dye viz. 20mg/L, 40mg/L and 60mg/L at pH 6.5 at the reaction temperature of 30 °C were selected for each adsorbent.

Figures 2a and 2b clearly reveals the extent of adsorption of dye on both adsorbents increases linearly with increase in concentration of the adsorbent and then remains constant.

**Effect of Temperature on kinetic rate constant and rate parameters**

For both adsorption processes, adsorption experiments were now carried out with fixed initial dye concentration (20mg/L) at pH 6.5 and at different temperature viz. 30 °C, 45 °C and 60 °C. The analysis of the data in (Table 2) reveals that the influence of temperature of the Rhodamine B has very little influence on the pseudo second order rate constants. The table 2 also reveals that the influence of the temperature of Rhodamine B on Elovich and pseudo first order rate constant is neither appreciable nor little.

It is obvious that the adsorption of Rhodamine B on the *Balsamadendron caudatum* wood activated carbon is best described by first order rate equation with regression coefficient value is greater than 0.97.

**Thermodynamic Parameter**

The thermodynamic parameters obtained for the adsorption systems were calculated using the following equation \(^{[20]}\):  

\[
\Delta G = -RT \ln K_c
\]

(11)

\[
\log K_c = \frac{\Delta S}{2.303} - \frac{\Delta H}{2.303 RT}
\]

(12)

\( K_c \) is equilibrium constant, \( C_{Ae} \) is the solid phase concentration at equilibrium, \( C_e \) is residual concentration (J/mole) and T is the temperature in Kelvin.

\( \Delta H \) and \( \Delta S \) were obtained from the slope and intercept of Vant Hoff plot (1/t Vs ln K). Table 3 gives the value of \( \Delta G, \Delta S \) and \( \Delta H \) for the adsorption of (BAC1 and BAC2). The negative values of free energy change (\( \Delta G \)) indicate the feasibility and spontaneous nature of adsorption of BAC1 and 2. The positive value of \( \Delta S \) is due to the increased randomness during the adsorption of adsorbents.
Mechanism

The high correlation coefficients obtained using pseudo first order and pseudo second order 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 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 dye, the dye 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 material [21].

It is now well established, that during the adsorption of dye over a porous adsorbent, the following three consecutive steps are taken place [22].
(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 compounds [23]. 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 ≈ 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 Rhodamine B to the transport of the adsorbed species from the solution to the pores of the adsorbent material and this step may control the rate of the adsorption process.

According to Michelson [24] for film diffusion to be rate-determining step, the value of the film diffusion coefficient, $D_f$ should be in the range $10^{-9}$ - $10^{-8}$ cm$^2$/sec. If pore diffusion were to the rate limiting, the pore diffusion coefficient, $D_p$, should be in the range $10^{-11}$ - $10^{-13}$ cm$^2$/sec. In order to find out the nature of the process responsible for adsorption on to chosen adsorbent, attempts were made to calculate the diffusion co-efficient of the process.

Assuming spherical geometry of the sorbents [25], the overall rate constant of the process can be correlated to the pore diffusion coefficient in accordance with the expression,

$$t_{1/2} = 0.03 \frac{r_o^2}{D_p}$$

or to the film diffusion coefficient in accordance with

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

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, $\bar{C}/C$ is equilibrium loading of the adsorbent, $\bar{\partial}$ 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 - 250μm), the average diameter of the particle was taken as 0.0215 x 10$^{-3}$ cm. Using these values, the film diffusion coefficients and pore diffusion coefficients were calculated. Then considering the pseudo first order rate constant $k_L$, for the adsorption of Rhodamine B. The values of $D_p$ and $D_f$ were calculated under the given set of operating conditions, and are presented in the Table 4.

The present study indicates the $D_p$ values in the order of $10^{-11}$ to $10^{-10}$ cm/sec and the $D_f$ values in the order of $10^{-10}$ to $10^{-9}$ for the respective Lagergren plots for Rhodamine B and hence, the investigator concludes that the mechanism of the removal of Rhodamine B in the present study by both adsorbents is complex.
The plot of $1/T$ versus log $D_i$ was found linear (not given) with negative slope indicating thereby the increase in the mobility of dye. This is due to the fact that with the rise in temperature the mobility of dye increases, which consequently decreases the retarding force acting on the diffusing dye.

Since both external Mass transfer and intraparticle diffusion constants varied with initial Rhodamine B concentration indicating the occurrence of both film diffusion and intra particle diffusion, the sorption data were further analyzed by the kinetic expression given by\(^\text{[26]}\) as

$$F = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[ -\frac{D_i \pi^2 n^2}{r^2} \right]$$

(15)

$$F = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[ -n^2 \beta \right]$$

(16)

Where $F$ is the fractional attainment of equilibrium at time $t$ and is obtained by using following equation and $n$ is the integer value.

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

(17)

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 equation \(\text{[27]}\). The $B_t$ vs time plots for the sorption of Rhodamine B over (BAC1 and BAC2) (Figure 3a and 3b) are found to be linear in beginning. Thus the process seems to be particle diffusion controlled in this region, while during the later deviation from linearity occurs and they also did not pass through the origin through out concentration range at $30, 45$ and $60^\circ$C. Thus the overall process can be interpreted as film diffusion.

From the slop of the straight line obtained from time versus $B_t$ graph, the $B$ value (time constant) were calculated. The values of effective diffusion coefficient ($D_i$) were calculated at different temperatures using the following Equation.

$$B = \frac{\pi^2 D_i}{r^2}, \text{ here 'r' is the radius of the absorbent particle. The Di values are given in the Table 5.}$$

The Values of energy of activation $E_a$, entropy of activation $\Delta S^\#$ and pre-exponential constant $D_0$ were calculated using following Equations.

$$D_i = D_0 \exp \left[ -\frac{E_a}{RT} \right]$$

(18)

$$D_0 = (2.72 d^2 kT/h) \exp \left[ \frac{\Delta S^\#}{R} \right]$$

(19)

Where $d$ is the average distance between the successive exchange sites and is taken as $5$ Å. $R, h$ and $k$ are the Gas, Planck, and Boltzmann constants, respectively. The values of $E_a, D_0, D_i, \Delta S^\#$ and other parameters are given in Table 5. The negative value of $\Delta S^\#$ reflects that no significant change occurs in the internal structure of chosen adsorbent during the adsorption process.

### Conclusion

Removal of Rhodamine B from aqueous solution was possible using several abundantly available low cost adsorbents. The adsorption of Rhodamine B was found to be dependent on pH, temperature and concentration for both adsorbents. Thermodynamic parameters obtained for both the adsorbents accounts for feasibility of the process at each concentration. Further the kinetic studies apparently reveal that the removal takes through a film diffusion process at all the concentrations and temperature for BAC1 as well as BAC2. The percentage saturation was found to be almost $95$ and $87\%$ for the (BAC1 and BAC2) respectively. The kinetics of Rhodamine B adsorption on different adsorbents was found to follow a pseudo second-order rate equation.

![Figure 1: Effect of pH on percentage of removal of Rhodamine B by (BAC1 and BAC2)](image_url)
Figure 2: Effect of concentration on adsorption of Rhodamine B over (a) BAC1 (b) BAC2 at pH 6.5.

Figure 3 (a)
Figure 3: Time vs $B_t$ plots different temperature of (a) Rhodamine B-BAC1 adsorption and (b) Rhodamine B-BAC2 adsorption

Table 1

Physico-chemical Characteristics of the Activated Carbon BAC1 & BAC2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BAC1</th>
<th>BAC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density (g/ml)</td>
<td>0.47</td>
<td>0.45</td>
</tr>
<tr>
<td>Ash content (%)</td>
<td>2.39</td>
<td>2.09</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>4.91</td>
<td>6.17</td>
</tr>
<tr>
<td>Surface area (m$^2$/g)</td>
<td>505</td>
<td>458</td>
</tr>
<tr>
<td>Solubility in water (%)</td>
<td>0.90</td>
<td>0.80</td>
</tr>
<tr>
<td>Solubility in 0.25M HCl (%)</td>
<td>1.19</td>
<td>1.16</td>
</tr>
<tr>
<td>Decolorizing power (mg/g)</td>
<td>48.5</td>
<td>40.3</td>
</tr>
<tr>
<td>Iodine number (mg/g)</td>
<td>453</td>
<td>212</td>
</tr>
<tr>
<td>pH $z_p$</td>
<td>4.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Carbonyl (mmol/g)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Lactonic (mmol/g)</td>
<td>0.037</td>
<td>0.038</td>
</tr>
<tr>
<td>Phenolic (mmol/g)</td>
<td>0.018</td>
<td>0.013</td>
</tr>
<tr>
<td>Acidic (mmol/g)</td>
<td>0.021</td>
<td>0.019</td>
</tr>
<tr>
<td>Basic (mmol/g)</td>
<td>0.393</td>
<td>0.412</td>
</tr>
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</table>

Table 2

The adsorption kinetic model rate constants for (BAC1 and BAC2) at different Temperature

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Initial Temperature</th>
<th>Pseudo order</th>
<th>Pseudo Second order</th>
<th>Elovich Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$k_1$</td>
<td>$r^2$</td>
<td>$k_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 min$^{-1}$</td>
<td></td>
<td>g mg$^{-1}$ min$^{-1}$</td>
</tr>
<tr>
<td>BAC1</td>
<td>30$^0$</td>
<td>0.205</td>
<td>0.978</td>
<td>0.0061</td>
</tr>
<tr>
<td></td>
<td>45$^0$</td>
<td>0.111</td>
<td>0.965</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td>60$^0$</td>
<td>0.186</td>
<td>0.957</td>
<td>0.029</td>
</tr>
<tr>
<td>BAC2</td>
<td>30$^0$</td>
<td>0.111</td>
<td>0.965</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td>45$^0$</td>
<td>0.117</td>
<td>0.960</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>60$^0$</td>
<td>0.136</td>
<td>0.957</td>
<td>0.029</td>
</tr>
</tbody>
</table>

(303)
### Table 3
Thermodynamic parameters for Rhodamine B, (BAC1 and BAC2) adsorption

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>$\Delta G \times 10^4$ (KJ mol$^{-1}$) $30^\circ$C</th>
<th>$\Delta H$ (KJ mol$^{-1}$)</th>
<th>$\Delta S$ (KJ mol$^{-1}$) $60^\circ$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAC1</td>
<td>-21.78</td>
<td>-32.27</td>
<td>48.63</td>
</tr>
<tr>
<td>BAC2</td>
<td>-11.75</td>
<td>-11.74</td>
<td>11.15</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Temperature, $^\circ$C</th>
<th>$t_{1/2}$, s</th>
<th>BAC1</th>
<th>BAC2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$D_p x 10^{-10}$, cm$^2$</td>
<td>$D_n x 10^{-9}$, cm$^2$</td>
<td>$D_p x 10^{-10}$, cm$^2$</td>
</tr>
<tr>
<td>30</td>
<td>3445.92</td>
<td>1.1410</td>
<td>6.813</td>
</tr>
<tr>
<td>45</td>
<td>4557.89</td>
<td>0.6983</td>
<td>5.545</td>
</tr>
<tr>
<td>60</td>
<td>4465.38</td>
<td>0.6621</td>
<td>5.174</td>
</tr>
</tbody>
</table>

### Table 5
Effective diffusion coefficient ($D_i$) pre exponential constants ($D_0$), activation energy ($E_a$) and entropy of activation $\Delta S^\theta$ for diffusion of Rhodamine B in BAC1 and BAC2

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>$D_i$ (m$^2$/s) $30^\circ$C</th>
<th>$D_i$ (m$^2$/s) $45^\circ$C</th>
<th>$D_i$ (m$^2$/s) $60^\circ$C</th>
<th>$D_0$ (m$^2$/s)</th>
<th>$E_a$ KJ/mol</th>
<th>$\Delta S^\theta$ JK$^{-1}$ mol$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAC1</td>
<td>1.22 x 10$^{-13}$</td>
<td>1.62 x 10$^{-13}$</td>
<td>3.41 x 10$^{-13}$</td>
<td>3.41 x 10$^{-6}$</td>
<td>45.8</td>
<td>-22.73</td>
</tr>
<tr>
<td>BAC2</td>
<td>4.2 x 10$^{-13}$</td>
<td>8.23 x 10$^{-13}$</td>
<td>9.69 x 10$^{-14}$</td>
<td>5.64 x 10$^{-4}$</td>
<td>25.4</td>
<td>-59.0</td>
</tr>
</tbody>
</table>

### References


