Global Journal of human social science
Geography & Environmental GeoSciences
Volume 12 Issue 10 Version 1.0 Year 2012
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-460X & Print ISSN: 0975-587X

Adsorptive Removal of Basic Dye Rhodamine B from Aquoeus Media onto Animal Bone Meal as New Low Cost Adsorbent

By Mohammadine El Haddad , Rachid Mamouni , Nabil Saffaj & Saïd Lazar
Université Cadi Ayyad ,Mohammedia, Maroc

Abstract - Adsorptive removal of a cationic dye – Rhodamine B – from aquoeus solutions was achieved by the use of Animal Bone Meal as a new low cost adsorbent. Adsorption of Rhodamine B was occured by studing the effects of contact time, adsorbent amount, dye concentration and temperature. Dye adsorption equilibrium was rapidly attained after 60 minutes of contact time. The isotherms of adsorption data were analyzed by Langmuir and Freundlich adsorption isotherm models. The adsorption capacity (Qm) obtained from the Langmuir isotherm plots were 62.11, 63.69, 64.13 and 64.95 mg/g respectively at 303, 313, 323 and 333°K. Thermodynamic parameters such as **Δ**H0, **Δ**S0 and **Δ**G0 were calculated, which indicated that the adsorption was spontanoeus and endothermic nature. The characteristic results and dimensionless separation factors RL showed that animal bone meal can be employed as an alternative to commercial adsorbents in the removal of Rhodamine B from aquoeus solution and wastewater.

Keywords : *Animal Bone Meal, Rhodamine B, Removal, Kinetics, Thermodynamic studies.*

GJHSS-B Classification : *FOR Code: 090403*

ADSORPTIVE REMOVAL OF BASIC DYE RHODAMINE B FROM AQUOEUS MEDIA ONTO ANIMAL BONE MEAL AS NEW LOW COST ADSORBENT

Adsorptive Removal of Basic Dye Rhodamine B from Aquoeus Media onto Animal Bone Meal as New Low Cost Adsorbent

Mohammadine El Haddad [α] , Rachid Mamouni [σ] , Nabil Saffaj [ρ] & Saïd Lazar [ω]

Abstract - Adsorptive removal of a cationic dye – Rhodamine B – from aqueous solutions was achieved by the use of Animal Bone Meal as a new low cost adsorbent. Adsorption of Rhodamine B was occured by studing the effects of contact time, adsorbent amount, dye concentration and temperature. Dye adsorption equilibrium was rapidly attained after 60 minutes of contact time. The isotherms of adsorption data were analyzed by Langmuir and Freundlich adsorption isotherm models. The adsorption capacity (Qm) obtained from the Langmuir isotherm plots were 62.11, 63.69, 64.13 and 64.95 mg/g respectively at 303, 313, 323 and 333°K. Thermodynamic parameters such as ΔH0, ΔS0 and ΔG0 were calculated, which indicated that the adsorption was spontaneous and endothermic nature. The characteristic results and dimensionless separation factors RL showed that animal bone meal can be employed as an alternative to commercial adsorbents in the removal of Rhodamine B from aqueous solution and wastewater.

Keywords : Animal Bone Meal, Rhodamine B, Removal, Kinetics, Thermodynamic studies.

I. INTRODUCTION

Dyes are widely used in various industries, such as textiles, paper, plastics, cosmetics and leather for coloring their final product. The release of colored wastewater from these industries may present an ecotoxic hazard and introduce the potential danger of bioaccumulation, which may eventually affect man throught the food chain. Wastewater containing even a small amount of dyes can severely affect the aquatic life due to the reduction of light penetration and their toxicity [1,2]. Due to the good solubility of dyes, they are common water polluants and they may frequently be found in trace quantities in industrial wastewaters. An indication of the scale of the problem is given by the fact that 2% of dyes produced annually are discharged in effluent from manufacturing operations, while 10% was discharged from textile and associated industries [3].

Many treatment methods have been investigated to remove dyes from wastewater. These methods can be divided into physical, chemical and biological methods. Adsorption has been observed to be an effective process for color removal from dye wastewater. Use of activated carbon has been found to be effective, but it is too expensive. Many studies have been under taken to investigate the use of low cost adsorbents [4-6].

The aim of the present study was to investigate the effect of the adsorbent amount, contact time, dye concentration and temperature on the adsorption of Rhodamine B dye onto animal bone meal. Both Langmuir and Freundlich isotherm models were used to describe the adsorption process. Kinetic and thermodynamic studies were achieved to determine the adsorption rate constants and thermodynamic parameters ΔG0, ΔH0 and ΔS0.

II. MATERIALS & METHODS

Rhodamine B (Rd-B) is the cationic dye used in this study, which was supplied from Fluka and was used without purification. The chemical structure of Rd-B is shown in Figure 1. Colored solutions were prepared by dissolving requisite quantity of Rd-B in distilled water. The final volume prepared was 500 mL. Adsorption studies for the evaluation of Animal Bone Meal (ABM) adsorbent for the removal of Rd-B dye from aqueous solutions were carried out in triplicate time using a batch contact adsorption method. Preliminary experiments demonstrated that the equilibrium was established at 55 min. A 50 mg sample of ABM was mixed with 50 mL dye solution of appropriate concentration. Samples of 10 mL of mixture were withdrawn from the batch at predetermined time intervals and the supernatant was centrifuged for 15 min at 3600 rpm. All dye solutions prepared were filtered by Millipore membrane type 0.45 μm HA, and the concentrations of dyes were determined from its UV/Visible absorbance characteristic with the calibration method. A BioMate 6, England UV/Visible spectrophotometer was used. A linear correlation was established between the dye concentration and the absorbance at $\lambda_{max} = 554$ nm, in the dye concentration

---

Author α : Equipe de Chimie Analytique & Environnement, Faculté Poly-disciplinaire, Université Cadi Ayyad, BP 4162, 46000 Safi, Maroc. Laboratoire de Biochimie, Environnement & Agroalimentaire, Faculté des Sciences & Techniques, Université Hassan II, BP 146, 20800 Mohammedia, Maroc. E-mail : elhaddad71@gmail.com

Author σ : Laboratoire de Chimie Organique, Equipe de Chimie Bio-Organique Appliquée, Faculté des Sciences,

Author ρ : Faculté Poly-disciplinaire d'Ouarzazate, Université Ibn Zohr, BP 8061, 80000 Agadir, Maroc.

Author ω : Laboratoire de Biochimie, Environnement & Agroalimentaire, Faculté des Sciences & Techniques, Université Hassan II, BP 146, 20800 Mohammedia, Maroc.

range (0 – 100 mg/L) with a good correlation coefficient $R^2 = 0.999$.

In order to characterise ABM, elemntal analysis, IR and X-Ray diffraction spectrums were studied. Elemental analysis of ABM shows a high yield of Ca (49.62%) and P (42.36%) with a (Ca/P) ratio equal to 1.17. Small amounts of Si (3.88%), Mg (1.32%), Na (0.77%), Al (0.35%), Fe (0.24%), Cl (0.24%), S (0.11%), K (0.07%), Sr (0.03%), Cu (0,03%) and Zn (0.02%) are found. The IR absorption spectrum of ABM depicted in Figure 2 shows bands characteristics of hydroxyapatite and more particularly a carbonated fluorapatite type B. We note the bands located between 1455 and 1430 cm-1, these waves numbers are comparable with those of carbonated fluorapatites Type B prepared according to the procedure used by Bonel [7]. Moreover, the IR shows independently of the bands of phosphates, bands located between 780 and 800 cm-1 which could appear from the vibration of silicates groups. X-ray diffraction analysis confirms the presence of hydroxyapatite as shown in Figure 3. The specific surface area of ABM was determined by BET method from adsorption - desorption isotherm of nitrogen at its liquid temperature 77°K and was found to be Sp = 85 m^2/g.

The amount of adsorption at time t, Qt (mg/g) was calculated using the following formula :

$$Q_t = \frac{C_0 - C_t}{W} V \qquad (1)$$

Where C_t (mg/L) is the liquid concentration of dye at any time, C_0 (mg/L) is the initial concentration of the dye in solution. V is the volume of the solution (L) and W is the mass of dye adsorbent (g).

The amount of equilibrium adsorption Q_e (mg/g) was calculated using the formula:

$$Q_e = \frac{C_0 - C_e}{W} V \qquad (2)$$

Where C_0 and C_e (mg/L) are the liquid concentrations of dye initially and at equilibrium.

The dye removal percentage can be calculated as follows:

$$\%ofdyeremoval = \frac{C_0 - C_e}{C_0} x100 \qquad (3)$$

Where C_0 and C_e (mg/L) are the initial and equilibrium concentrations of dye in solution.

To understand the adsorption mechanism, it was necessary to determine the zero point charge pH (pH_{ZPC}) of the adsorbent. The pH_{ZPC} of ABM was measured using the pH drift method [8]. In this fact, the pH_{ZPC} of the adsorbent was determined by adding 20 mL of 5.10^{-2} mol/L NaCl to several 50 mL cylindrical high-density polystyrene flasks (height 117 mm and diameter 30 mm). A range of initial pH (pH_i) values of the NaCl solutions were adjusted from 2 to 12 by adding 10^{-1} mol/L of HCl and NaOH. The total volume of the solution in each flask was brought to exactly 30 mL by further addition of 5.10^{-2} mol/L NaCL solution. The pH_i values of the solutions were then accurately noted and 50 mg of each adosrbent were added to each falsk, which was securely capped immediately. The suspensions were shaken in a shaker at 298°K and allowed to equilibrate for 48 hours. The suspensions were then centrifuged at 3600 rpm for 15 min and the final pH (pH_f) values of the supernatant liquid were recorded. The value of pH_{ZPC} is the point where the curve of ΔpH ($pH_f - pH_i$) versus pH_i crosses the line equal to zero. In this study, the determination of pH_{ZPC} of ABM was depicted in Figure 4 and was found to be 8.4 .

III. RESULTS AND DISCUSSION

a) Effect of contact time and initial dye concentration onto the removal dye

In order to achieve accurate effect of contact time and Rd-B concentration, we have used initially a concentration dye of 60 mg/L, 50 mg of ABM quantity and 50 mL as solution volume. The results are expressed with percentage removal of Rd-B versus differents contact time in the range 10 – 90 minutes and are depicted in Figure 5. Percentage removal of Rd-B increases when increasing contact time and occurs that the adsorption equilibrium of Rd-B was rapidly attained after 60 minutes of contact time. Figure 5 reveals that the curve is single, smooth and continoeus leading to saturation, that suggesting the possible monolayer coverage of Rd-B onto ABM. In the second hand, we have achieved the effects of concentrations Rd-B (20, 40, 60, 80 and 100 mg/L) and temperature (303, 313, 323 and 333°K) on the percentage of removal dye. Table 1 depicts the different liquid concentrations of dye at equilibrium C_e (mg/L), amount of equilibrium adsorption Q_e (mg/g) and percentage of removal dye versus concentration Rd-B and temperature. At constant temperature, increasing concentration Rd-B causes an increasing of concentrations dye at equilibrium and amount of equilibrium adsorption. It means that the adsorption is hightly dependent on initial concentration of dye. The best percentage of removal Rd-B was observed at lower concentration dye. It is because of the fact at lower concentration, the ratio of the initial number of dye molecules to the availlable surface area is low subsequently the fractional adsorption becomes independent of initial concentration. However, at high concentration the availlable sites of adsorption becomes fewer and hence the percentage removal of dye dependents upon concentration. At constant concentration dye, the increasing of temperature decreases the concentration of dye at equilibrium and increases simultanoeusly the amount of equilibrium adsorption and the percentage of removal Rd-B.

b) *Effect of adsorbent dose onto the adsorption of Rd-B*

To evaluate the effect of adsorbent dose on the adsorption of Rd-B, we have used 60 mg/L as initial concentration Rd-B and 50 mL of solution volume. Figure 6 depicts the variation of percentage of removal Rd-B versus adsorbent dose from the range of (10 – 90 mg). The percentage of removal Rd-B increases with increasing adsorbent dose. The decolorization of aquoeus solutions by Rd-B varied from 37% to 84% when the adsorbent dose increases from 10 to 90 mg. This was attributed to increased ABM surface area and availlability of more adsorption sites. Hence, the following experiments were carried out with the adsorbent dose of 50 mg using 50 mL of solution volume.

c) *Adsorption isotherm*

The adsorption isotherm is the most important information which indicates how the adsorbate molecules distribute between the liquid phase and the solid phase when the adsorption process reaches an equilibrium state. To optimize the design of an adsorption system for the adsorption of adsorbates, it is important to establish the most appropriate correlation for the equilibrium curves. The experimental data were analyzed according to linear form of the Langmuir and Freundlich isotherms [9,10]. The linear form of Langmuir isotherm is expressed as:

$$\frac{C_e}{Q_e} = \frac{C_e}{Q_m} + \frac{1}{Q_m b} \qquad (4)$$

Where C_e is the equilibrium concentration of dye in solution (mg/L), Q_e is the amount of dye adsorbed per unit weight of adsorbent at equilibrium (mg/g), Q_m is the monolayer adsorption capacity (mg/g) and b is related with the energie of the adsorption (L/mg). Plots of C_e/Q_e versus C_e yield a straight line with slope $1/Q_m$ and intercept $1/Q_m b$ suggest the applicability of the Langmuir isotherm at different temperatures (Figure 7). Table 2 Lists the maximum adsorption capacity Q_m values for Rd-B adsorption onto ABM at different temperatures. From the results, it is clear that the value of adsorption efficiency Q_m and adsorption energy b of the ABM increases when increasing the temperature. From the values it is concluded that the maximum adsorption corresponds to a saturated monolayer of adsorbate molecules on adsorbent surface with constant energy and no transmission of adsorbate in the plane of the adsorbent surface. The observed b value shows that the adsorbent prefers to bind acidic ions and that speciation predominates on sorbent characteristics, when ion exchange as the predominant mechanism takes place in the adsorption of Rd-B, it confirms the endothermic nature process involved in the system. The essential characteristics of the Langmuir isotherm can be expressed in terms of dimmensioless constant separation factor R_L given by [11,12]:

$$R_L = \frac{1}{1 + bC_0} \qquad (5)$$

Where L is the Langmuir constant and C_0 is the highest initial dye concentration (mg/L).

R_L values indicate the type of Langmuir isotherm and to be [11,12]:

Irreversible: $R_L = 0$

Favorable: $0 < R_L < 1$

Linear: $R_L = 1$

Unfavorable: $R_L > 1$

According to the values of R_L calculated at 303, 313, 323 and 333°K are in range between 0 and 1 and are given in Table 3, which indicates that the adsorption process is favorable at operation conditions studied.

The Freundlich isotherm is an empirical equation based upon a heterogeneous surface [13]. A linear form of the Freundlich expression can be presented as below:

$$\log Q_e = \log K_f + \frac{1}{n}\log C_e \qquad (6)$$

A plot of log Q_e versus log C_e enables to determine the constant K_f and n. K_f represents the quantity of dye adsorbed onto adsorbent for an equilibrium concentration. The slope n ranging between 0 and 1, is a measure of adsorption intensity or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero. These values together with the correlation coefficients are summarized in Table 2.

d) *Determination of thermodynamic parameters*

The adsorption capacity of ABM increased with increase in the temperature of the system from 303 – 333°K. Thermodynamic parameters such as change in free energy ΔG^0 (kj/mol), enthalpy ΔH^0 (kj/mol) and entropy ΔS^0 (kj/°K.mol) were determined using the following equations:

$$K_0 = \frac{C_{solid}}{C_{liquid}} \qquad (7)$$

$$\Delta G^0 = -RT \ln K_0 \qquad (8)$$

$$\log K_0 = \frac{\Delta S^0}{2.303R} - \frac{\Delta H^0}{2.303RT} \qquad (9)$$

Where K_0 is the equilibrium constant, C_{solid} is the solid phase concentration at equilibrium (mg/L), C_{liquid} is the liquid phase concentration at equilibrium (mg/L), T is the temperature expressed in ° Kelvin and R is the gas constant. The ΔH^0 and ΔS^0 values obtained from the slope and intercept of Van't Hoff plots are presented in Table 4. The values of ΔH^0 are within the range of 1 – 93 kj/mol indicating the physisorption. From these results it is clear that physisorption is much more favourable for the adsorption of Rd-B. The positive values of ΔH^0 show the endothermic nature of adsorption and it governs the possibility of physical adsorption [14-16]. Since in case of physical adsorption, while increasing the temperature of the system, the extent of Rd-B adsorption increases, this rules out the possibility of chemiosorption [17,18]. The low value of ΔH^0 suggests that the Rd-B is physisorbed onto ABM adsorbent.

The negative values of ΔG^0 (Table 4) shows that the adsorption is highly favourable and spontaneous. The positive values of ΔS^0 (Table 4) shows the increased disorder and randomness at the solid solution interface of Rd-B with ABM adsorbent that bring about some structural changes in the Rd-B and the ABM. The enhancement of adsorption capacity of the ABM at higher temperatures was attributed to the enlargement of pore size and activation of the adsorbent surface [19,20].

e) *Study of kinetics adsorption*

In present study, the kinetics studies of dye removal was carried out to understand the behaviour of the low cost ABM adsorbent. The adsorption of dye from aquoeus media by the adsorbent follows reversible first order kinetics, when a single species is considered on a heterogeneous surface. The heterogeneous equilibrium between the Rd-B solutions and the ABM is expressed as:

$$(\text{Rd-B})_{\text{Liq}} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} (\text{Rd-B})_{\text{Sol}}$$

Where k_1 is the forward rate constant and k_2 is the backward rate constant. $(\text{Rd-B})_{\text{Liq}}$ represents dye remaining in the aquoeus solution and $(\text{Rd-B})_{\text{Sol}}$ represents dye adsorbed on the surface of ABM. The equilibrium constant K_0 is the ratio of adsorbate concentration in adsorbent and in aquoeus solution:

$$K_0 = k_1/k_2 \tag{10}$$

In order to achieve the kinetics of the adsorption process, we have used the following kinetic equation [21,22]:

$$\log\frac{C_0}{C_t} = \frac{k_{ads}}{2.303}t \tag{11}$$

Where C_0 and C_t are the concentration of the dye (mg/L) at time zero and at time t, respectively. The rate constant (k_{ad}) for the adsorption processes have been calculated from the slope of the linear plots of log C_0/C_t versus t for different concentrations and temperatures. The determination of rate constants as described in literature is given as:

$$k_{ads} = k_1 + k_2 = k_1 + \frac{k_1}{K_0} = k_1\left(1 + \frac{1}{K_0}\right) \tag{12}$$

Table 5 depicts the overall rate constants kad for the adsorption of Rd-B at different temperatures are found from the slope of the plots of equation (11). From these values shown in Table 5, the rate constant kad increases with increase in temperature suggesting that the adsorption process is endothermic nature. Further, kad values decrease with increasing initial concentration of the Rd-B. In cases of strict surface adsorption a variation of rate should be proportional to the first power of concentration. However, when pore diffusion limits the adsorption process, the relationship between initial dye concentration and rate of reaction will not be linear. Thus, in the present study pore diffusion limits the overall rate of Rd-B adsorption. The overall rate of adsorption is separated into the rate of forward and reverse reactions using the above equation. The rate constants of forward and reverse processes are also collected in Table 5. It indicates that at all initial concentrations and temperatures, the forward rate constant is much higher than the reverse rate constant suggesting that the rate of adsorption is clearly dominant.

IV. Conclusion

The results indicated that ABM is a promising new low cost adsorbent for removal of Rhodamine B from aqueous solutions. The equilibrium data have been analyzed. The results showed that the Rhodamine B flollowed Langmuir isotherm model. Thermodynamic studies indicated that the dye adsorption onto ABM was a spontaneous, endothermic and physical reaction.

References Références Referencias

1. I.M. Banat, P. Nigam, D. Singh, R. Marchant. Microbial decolorization of textile dye containing effluents. Bioresource Technology 58 (1996) 217 – 227.
2. T. Robinson, G. MacMullan, R. Marchant, P. Nigam. Remediation of dyes textile effluent: a critical review on current treatment technologies with a proposed alternative. Bioresource Technology 77 (2001) 247 – 255.
3. J.R. Easton. Colour in dye house effluent. P. Copper (Ed.), Soc. Dyes, Colorists, The Alden Press, Oxford (1995).
4. G. Crini. Non-conventional low cost adsorbents for dye removal. Bioresource Technology 97 (2006) 1061 – 1085.

5. V.K. Gupta, Suhas. Application of low cost adsorbents for dye removal. Journal of Environmental Managmenet 91 (2009) 2313 – 2342.
6. Srinivasan, T. Viraraghavan. Decolorization of dye wastewaters by biosorbents. Journal of Environmental Managmenet 91 (2010) 1915 – 1929.
7. G. Bonel. Annales Chimie 7 (1972) 127 – 144.
8. T. Calvete, E. C. Lima, N. F. Cardoso, S. L. P. Dias, F. A. Pavan. Applications of carbon adsorbents prepared from the Brazilian-pine fruit shell for removal of Procion Red MX 3B from aquoeus solution : kinetic, equilibrium and thermodynamic studies. Chemical Engineering Journal 155 (2009) 627 – 636.
9. I.Langmuir. The constitution and fundamental proporties of solids and liquids . Journal of the American Chemical Society 38 (1916) 2221 – 2295.
10. H.J. Butt, K. Graf. Physics and Chemistry of interfaces. Wiley-VCH. Weinheim, 2003. pp. 185 – 193.
11. F. Deniz, S. Karaman. Removal of Basic Red 46 dye from aquoeus solution by pine tree leaves. Chemical Engineering Journal 170 (2011) 67 – 74.
12. Y. Safa, H.N. Bhatti. Kinetic and thermodynamic modeling for the removal of Direct Red 31 and Direct Orange 26 dyes from aqueous solutions by rice husk. Desalination 272 (2011) 313 – 322.
13. N.M. Mahmoodi, B. Hayati, M. Arami, C. Lan. Adsorption of textile dyes on Pine Cone from colored wastewater : Kinetic, equilibrium and thermodynamic studies. Desalination 268 (2011) 117 – 125.
14. A.R. Cestari, E.F.S. Vieira, A.M.G. Tavares, R.E. Bruns The removal of the indigo carmine dye from aqueous solutions using cross-linked chitosan-Evaluation of adsorption thermodynamics using a full factorial design. Journal of Hazardous Materials 153 (2008) 566 – 574.
15. I.D. Mall, V.C. Srivastava, N.K. Agarwal Removal of Orange-G and Methyl Violet dyes by adsorption onto bagasse fly ash: kinetic study and equilibrium isotherm analyses. Dyes and Pigments 69 (2006) 210 – 223.
16. A.Altınısık, E. Gür, Y. Seki A natural sorbent, Luffa cylindrica for the removal of a model basic dye. Journal of Hazardous Materials 179 (2010) 658 – 664.
17. S.D. Khattri, M.K. Singh Removal of malachite green from dye wastewater using neem sawdust by adsorption. Journal of Hazardous Materials 167 (2009) 1089 – 1094.
18. S.V. Mohan, N.C. Rao, J. Karthikeyan Adsorptive removal of direct azo dye from aqueous phase onto coal based sorbents: a kinetic and mechanistic study. Journal of Hazardous Materials B90 (2002) 189 – 204.
19. M. Arami, N.Y. Limaee, N.M. Mahmoodi Evaluation of the adsorption kinetics and equilibrium for the potential removal of acid dyes using a biosorbent. Chemical Engineering Journal 139 (2008) 2 – 10.
20. V.K. Garg, R. Gupta, A.B. Yadav, R. Kumar Dye removal from aqueous solution by adsorption on treated sawdust. Bioresource Technology 89 (2003) 121 – 124.
21. A.Gil, F.C.C. Assis, S. Albeniz, S.A. Korili Removal dyes from wastewaters by adsorption on pillared clays. Chemical Engineering Journal 168 (2011) 1032 – 1040.
22. M.A. Ahmad, N.K. Rahman Equilibrium, kinetics and thermodynamic of Remazol Brillant Orange 3R dye adsorption on coffee husk-based activated carbon. Chemical Engineering Journal 170 (2011) 154 – 161.

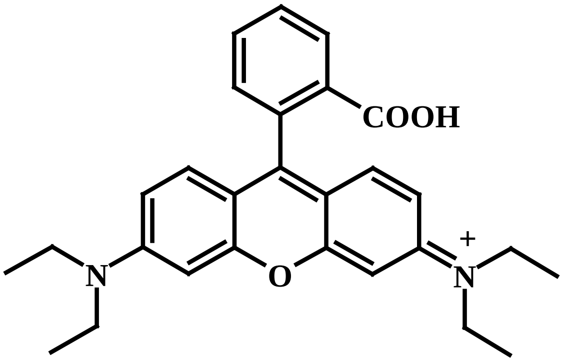

Figure 1 : Chemical structure of Rhodamine B.

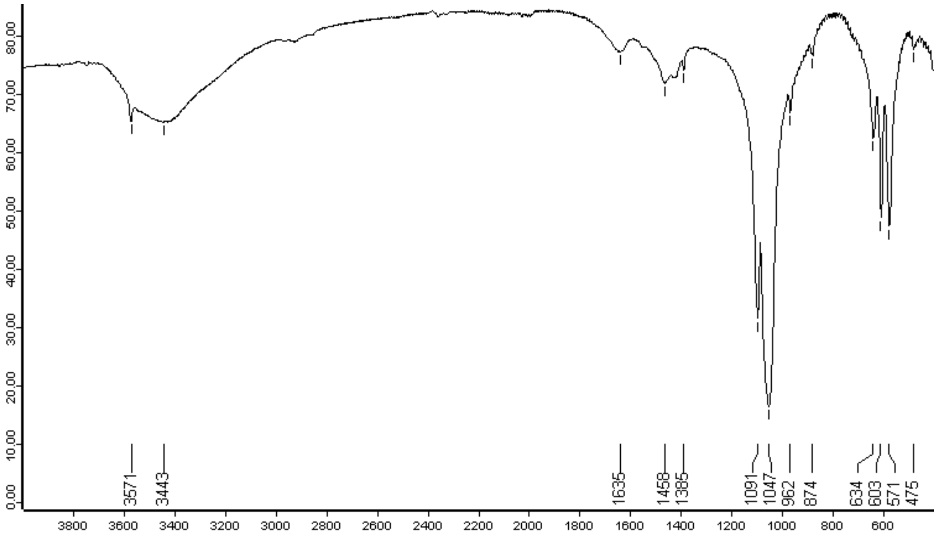

Figure 2 : IR spectra of ABM.

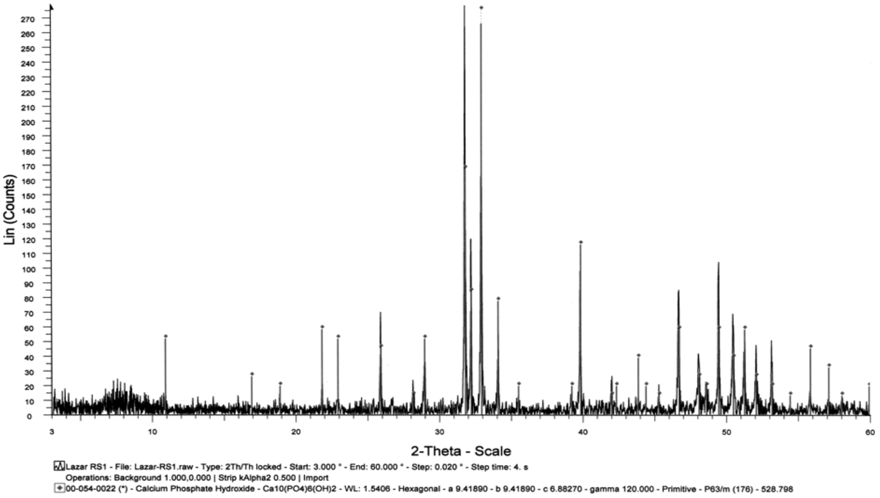

Figure 3: X-ray diffraction of ABM.

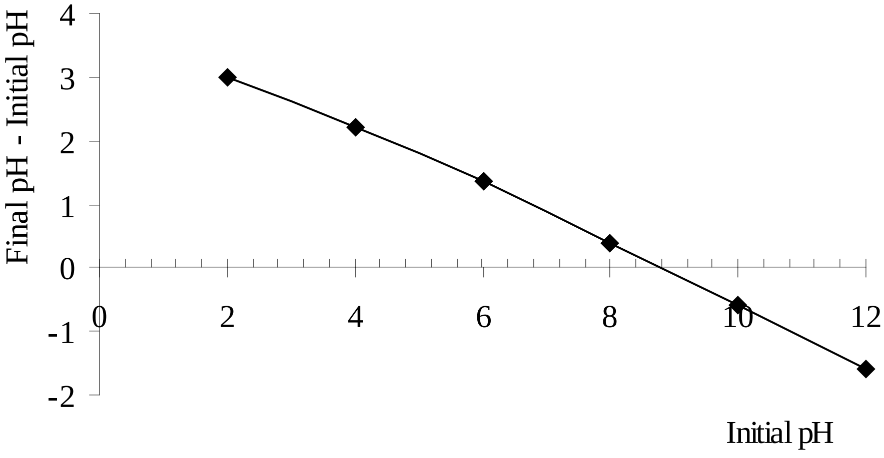

Figure 4 : Determination of Zero Point Charge pH.

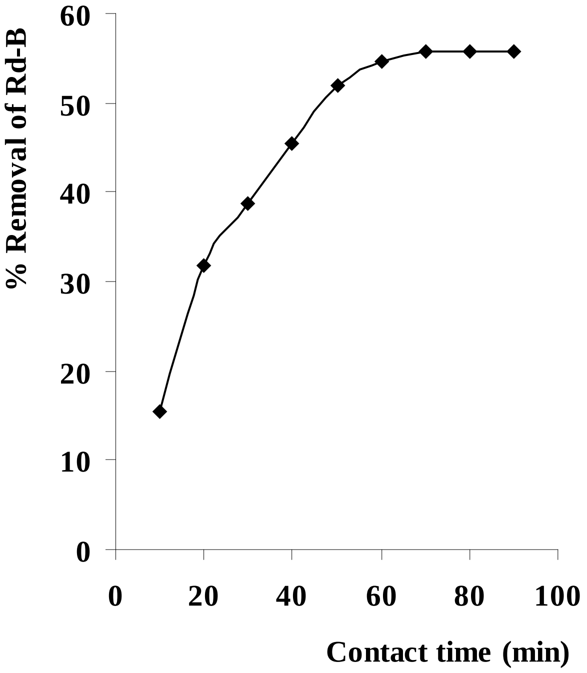

Figure 5 : Effect of contact time on the adsorption of Rd-B. [Rd-B] = 60 mg/L ; Adsorbent dose : W = 50 mg and V = 50 mL.

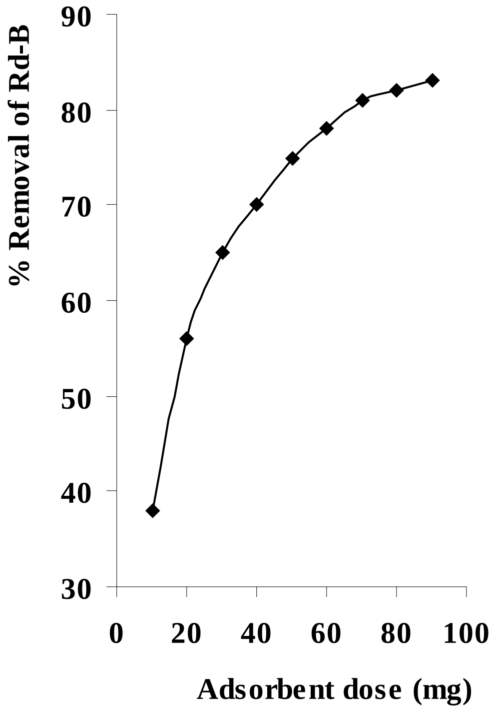

Figure 6 : Effect of adsorbent dose on the adsorption of Rd-B :[Rd-B] = 60 mg/L ; Contact time = 60 min

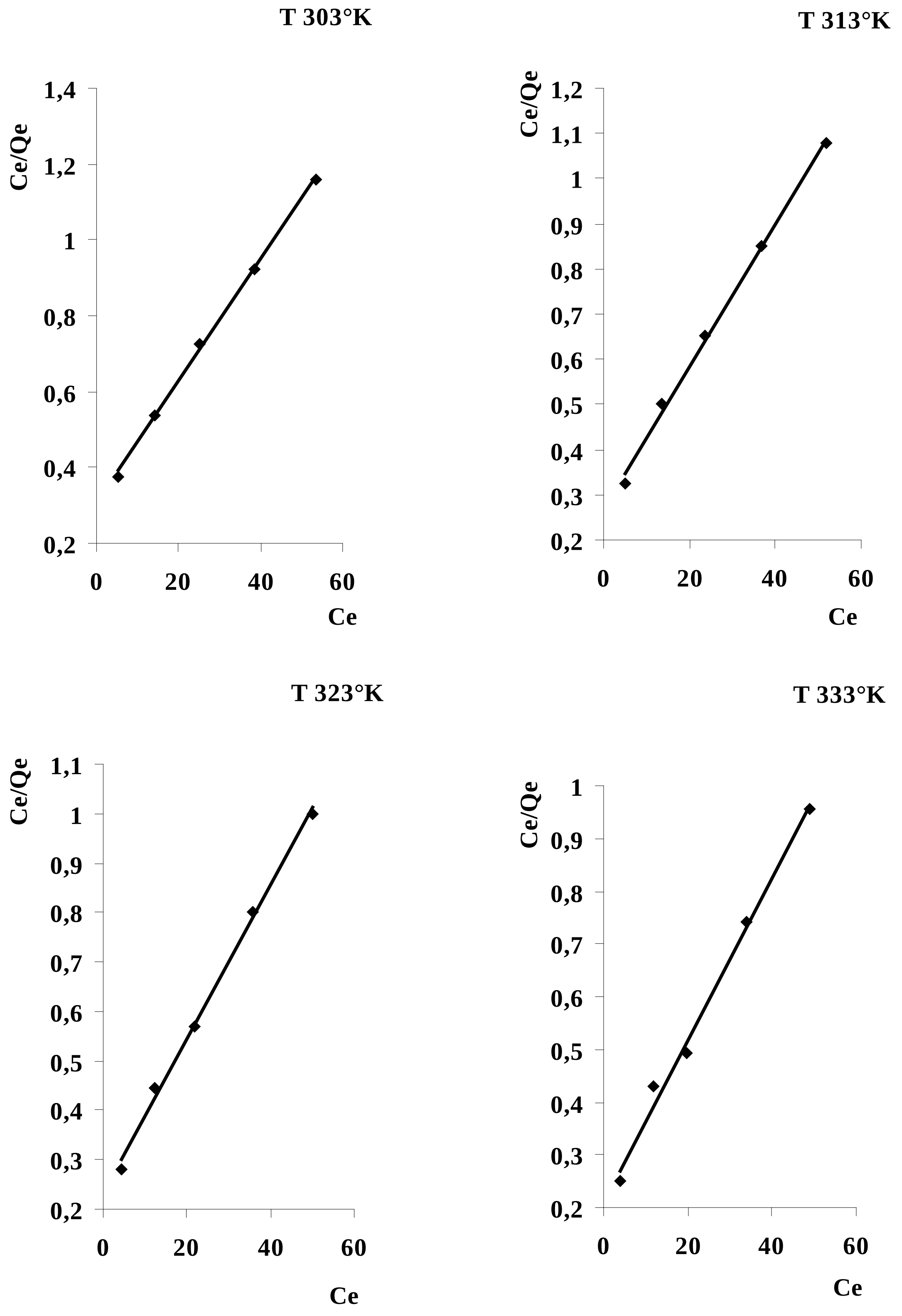

Figure 7 : Linear Langmuir isotherm for the adsorption of Rd-B onto ABM.

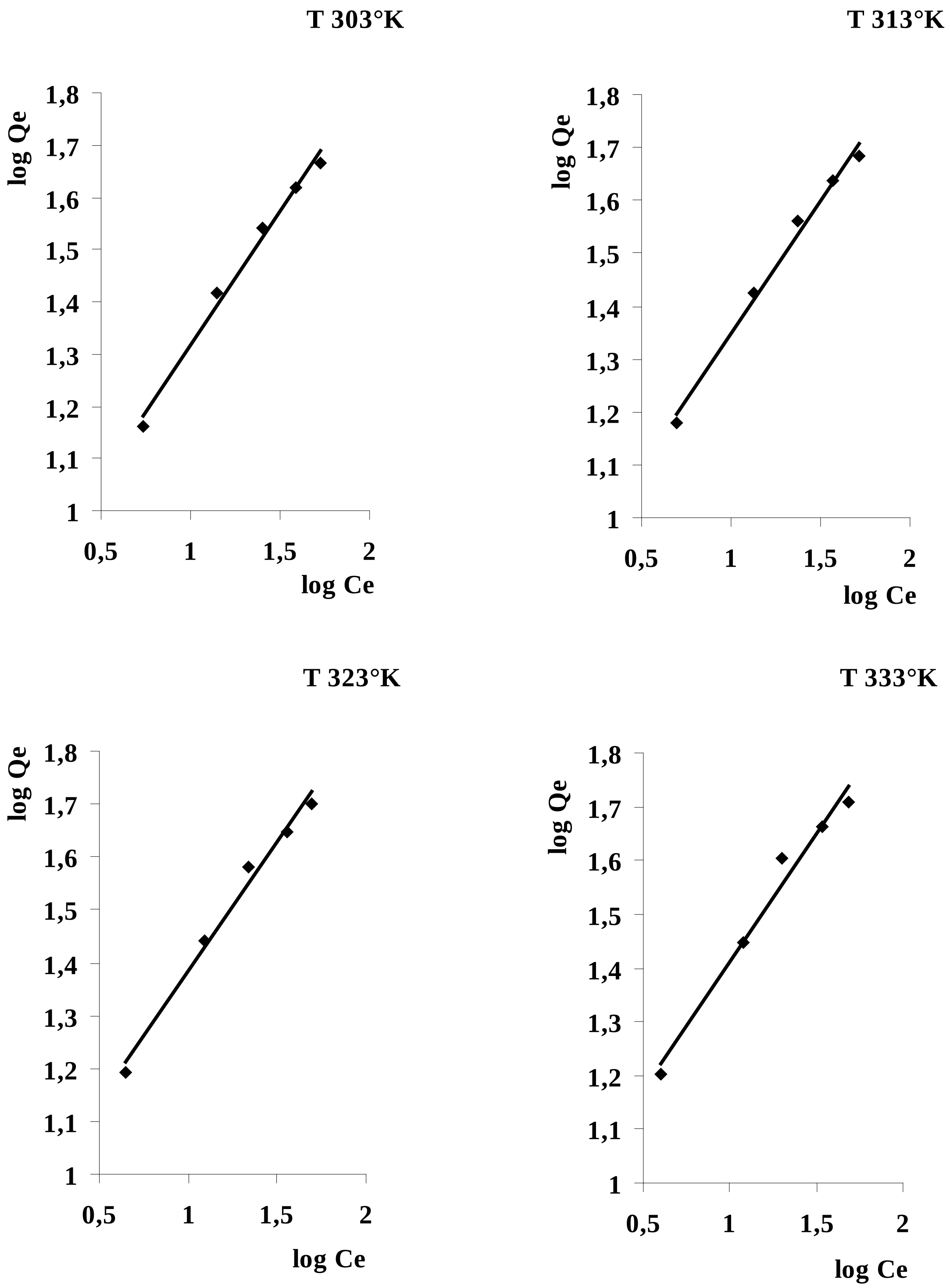

Figure 8 : Linear Freundlich isotherm for the adsorption of Rd-B onto ABM.

$[Rd\text{-}B]_0$ (mg/L)		20	40	60	80	100
C_e (mg/L)	303°K	5.4532	13.9876	25.2347	38.3456	53.6754
	313°K	4.9178	13.3567	23.6543	36.7456	51.8765
	323°K	4.4024	12.3425	21.7654	35.5643	49.9876
	333°K	4.0034	12.0125	19.7895	34.0453	48.8976
Q_e (mg/g)	303°K	14.5468	26.0124	34.7653	41.6544	46.3246
	313°K	15.0822	26.6433	36.3457	43.2544	48.1235
	323°K	15.5976	27.6575	38.2346	44.4357	50.0124
	333°K	15.9966	27.9875	40.2105	45.9547	51.1024
% Removal Dye	303°K	72.73	65.03	57.94	52.07	46.32
	313°K	75.41	66.61	60.58	54.07	48.12
	323°K	77.99	69.14	63.72	55.54	50.01
	333°K	79.98	69.97	67.02	57.44	51.10

Table 1 : Equilibrium parameters for the adsorption of dye onto ABM adsorbent.

	Langmuir isotherm results			Freundlich isotherm results		
Temp. °K	R^2	Q_m (mg/g)	b	R^2	K_f	n
303	0.9982	62.11	0.053	0.9883	6.41	1.96
313	0.9971	63.69	0.058	0.9899	7.05	2.00
323	0.9964	64.13	0.067	0.9861	8.35	2.06
333	0.9956	64.95	0.074	0.9762	8.61	2.10

Table 2 : Statistical parametrs/constants of Langmuir and Freundlich isotherms results.

[Rd-B] (mg/L)	Temperature °K			
	303	313	323	333
20	0.484	0.463	0.427	0.403
40	0.321	0.301	0.272	0.253
60	0.240	0.223	0.200	0.184
80	0.191	0.177	0.157	0.146
100	0.159	0.147	0.130	0.120

Table 3 : Dimensionless separation factor R_L.

$[Rd\text{-}B]_0$ (mg/L)		20	40	60	80	100
K_0	303°K	2,67	1,86	1,38	1,12	1,09
	313°K	3,07	1,99	1,54	1,18	1,10
	323°K	3,54	2,24	1,76	1,25	1,12
	333°K	4,00	2,33	2,03	1,35	1,15
ΔG^0 (kJ/mol)	303°K	- 2.474	- 1.563	- 0.811	- 0.285	- 0.218
	313°K	- 2.919	- 1.791	- 1,124	- 0.431	- 0.248
	323°K	- 3.395	- 2.166	- 1.518	- 0.599	- 0.304
	333°K	- 3.838	- 2.342	- 1.960	- 0.831	- 0.387
ΔH^0 (kJ/mol)	-------	14.76	12.46	6.76	5.97	5.05
ΔS^0 (kJ/°K.mol)	-------	30.78	25.56	23.28	19.47	17.67

Table 4 : Equilibrium constant and thermodynamic parameters for the adsorption of Rhodamine B onto ABM adsorbent

$[Rd\text{-}B]_0$ (mg/L)		20	40	60	80	100
303°K	k_{ad}	3.93	3.65	3.52	3.48	3.32
	k_1	2.96	2.36	2.04	1.84	1.73
	k_2	0.97	1.29	1.48	1.64	1.58
313°K	k_{ad}	4.64	4.19	3.95	3.86	3.69
	k_1	3.50	2.79	2.39	2.09	1.93
	k_2	1.14	1.40	1.56	1.77	1.76
323°K	k_{ad}	4.97	4.73	4.55	4.18	3.88
	k_1	3.88	3.27	2.90	2.32	2.05
	k_2	1.09	1.46	1.65	1.86	1.83
333°K	k_{ad}	5.17	4.87	4.65	4.51	4.48
	k_1	4.14	3.41	3.12	2.59	2.40
	k_2	1.03	1.46	1.53	1.92	2.08

3 -1

Table 5 : Rate constants for the adsorption of Rhodamine B (10^3 k_{ad}, min^{-1}) and the constants for forward (10^3 k_1,min^{-1}) and reverse (10^{3} k_2, min^{-1}) process

This page is intentionally left blank