



Adsorption, Kinetic, Equilibrium and Thermodynamic studies on the removal of basic dye Rhodamine-B from aqueous solution by the use of natural adsorbent perlite

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Abstract

This paper presents the feasibility of removal of basic dye Rhodamine-B from aqueous solutions by using a low cost natural adsorbent perlite. Batch adsorption experiments were carried out as a function of pH, contact time, initial concentration of the adsorbate, adsorbent dosage and temperature. Dye adsorption equilibrium was rapidly attained after 50 minutes of the contact time, and it was described by the Langmuir and Freundlich adsorption isotherms over the entire concentration ranges from 20-100 mgL⁻¹. Adsorption data's are used for modelling, from the first and second order kinetic equation and intra-particle diffusion models. Thermodynamic parameters such as ΔH° , ΔS° , and ΔG° were calculated, which indicated that the adsorption was spontaneous and exothermic nature, which was evident by decreasing the randomness of the dye at the solid and liquid interface. Adsorbent used in this study, characterized by FT-IR and SEM before and after the adsorption of Rhodamine-B. The characteristic results and dimensionless separation factors (R_L) showed that perlite can be employed as an alternative to commercial adsorbents in the removal of Rhodamine-B from aqueous solution and waste water.

Keywords: Rhodamine-B, perlite, adsorption isotherm, kinetics, minerals

1. Introduction

During the last few decades the mobility and distribution of dyes in water have been studied extensively due to their toxic effects to humans, animals, plants and the aquatic organisms. Many of the industries, such as dyestuffs, textile, paper, leather, foodstuffs, cosmetics, rubber and plastics are using enormous quantity of synthetic dyes in order to give colour for their products and consume substantial volumes of water. As a result, they generate a considerable amount of coloured wastewater. Textile and dyeing industry are among important sources for the continuous pollution of the aquatic environment. Because they produce approximately 5% of them end up in effluents. The textile and dyeing industries effluents are discarded into rivers, ponds and lakes; they affect the biological life various organisms [1-3]. Dye-containing effluents are undesirable wastewaters because they contain high levels of chemicals, suspended solids, and toxic

compounds [4,5]. Colour causing compounds can react with metal ions to form substances which are very toxic to aquatic flora and fauna and cause many water borne diseases [6-8].

Due to the chemical structure of dye, they act as a resistant to many chemicals, oxidizing agents, and heat, and are biologically non-degradable. So it is difficult to decolorize the effluents, once released into the aquatic environment. Many of the methods are available for the removal of pollutants from water, the most important of which are reverse osmosis, ion exchange, precipitation and adsorption. Of these methods, adsorption technique is a most versatile and widely used technique [9-14], because of its inexpensive nature and ease of use. The advantages and disadvantages of each method have been extensively reviewed by Lorenc et al., [15] and Cooper [16]. Many studies have been undertaken for the removals of pollutants by using variety of materials are used as adsorbents [17-28].

Activated carbon is extensively used as an adsorbent due to its high level of effectiveness, but it is more expensive and has high usage costs. This has led many researchers to search for inexpensive and locally available adsorbents so that the process can become economically feasible. In this study, the use of perlite as an adsorbent for the removal of a basic dye, Rhodamine B, is proposed. Perlite is a naturally occurring glassy volcanic siliceous rock, when it is heated to a suitable temperature, expands to form a lightweight, glasslike material with a cellular structure.

The expanded perlite finds use in the construction industry (65%), horticultural markets (11%), as filter aids and filters (22%), and other industrial applications (2%). The variation in adsorption capacity of different perlite samples is due to chemical composition, micro-morphology, and surface charges [29]. Studies have been carried out on methylene blue, basic blue 41, and organic solute adsorption using perlite as a sorbent [30-33]. The objective of the present study is, to remove the basic dye Rhodamine-B from aqueous solution by using a low cost natural adsorbent perlite. In the batch mode studies, the dynamic behaviour of the adsorption was investigated on the effect of initial metal ion concentration, temperature, adsorbent dosage and pH. The thermodynamic parameters were also evaluated from the adsorption measurements. The Langmuir, Freundlich and Tempkin adsorption isotherms, adsorption Kinetics, FT-IR spectroscopy and SEM were also studied. Double distilled water was used throughout the experiment.

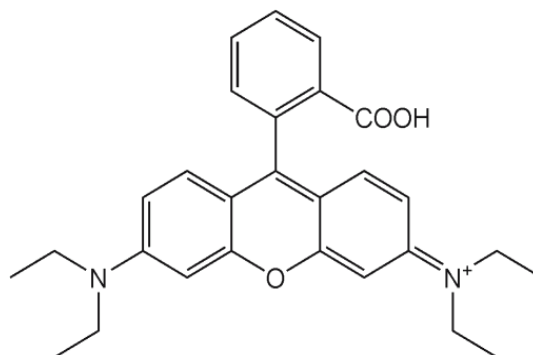
2. Materials and Methods

2.1. Sorbent

The adsorbent perlite (Expanded) was purchased from Rajasthan Barites Ltd., an ISO 9001-2000 company Udaipur, North India, and originated in Asian-European countries including Greece, Japan, and Turkey. The composition of the perlite was SiO₂ - 71 to 75%, Al₂O₃ - 12 to 16%, Na₂O - 2.9 to 4.0%, K₂O - 4 to 5%, CaO - 0.5 to 2.0%, Fe₂O₃ - 0.5 to 1.45%, MgO - 0.03 to 0.5%, TiO₂ - 0.03 to 0.2%, MnO₂ - 0.0 to 0.1%, SO₃ - 0.0 to 0.1%, FeO - 0.0 to 0.1%, Ba - 0.0 to 0.1%, PbO - 0.0 to 0.5%, and Cr - 0.0 to 0.1%. The perlite samples were treated before use as follows [20]. A mixture containing 10g L⁻¹ perlite was mechanically stirred for 24 hours. After about two minutes, the supernatant was filtered through a white band filter paper. The solid sample was dried at 110 °C for 24h, and then sieved by a 100 mesh sieve. The particle smaller than 100-mesh size were used in the experiment.

2.2. Sorbate

The commercial-grade basic dye Rhodamine-B [C.I.No - 45170; C.I.Name - basic violet 10, chemical formula - C₂₈H₃₁ClN₂O₃; molecular weight - 479.02 g/mol; λ_{max} - 543 nm], was used and supplied by S. D. Fine Chemicals, Mumbai, India.



Structural formula of Rhodamine-B

All other chemicals used were of analytical reagent grade. 1 gL⁻¹ of stock solution was prepared by dissolving the dye with double distilled water. Experimental solutions in the desired concentrations were prepared from the stock solution by subsequent dilution.

2.3. Experimental Methods

In each adsorption experiment, 50 mL of dye solution with a known concentration was added to 0.05 g of perlite in a 250 mL glass-stoppered flask at 30 ± 0.5 °C, and the mixture was stirred on a mechanical shaker at 150 min⁻¹. The samples were withdrawn during stirring at preset time intervals, and the adsorbent was separated from the solution by centrifugation (Research Centrifuge, Remi Scientific Works, Mumbai) at 4500 min⁻¹ for 5 min. The absorbance of the supernatant solution was estimated to determine the residual dye concentration, and was measured before and after treatment with double beam spectrophotometer (HITACHI U 2000 Spectrophotometer). All experiments were carried out twice, and the concentrations given are average values. The initial dye concentration in the test solution and the adsorbent dosage were varied to investigate their effect on the adsorption kinetics. The effect of pH was observed by studying the adsorption of dye over the pH range from 3 to 13. The pH of the dye solution was adjusted by using NaOH or HCl solution and a pH meter. The sorption studies were carried out at different temperatures (30^o, 40^o, 50^oC). This is used to determine the effect of temperature on the thermodynamic parameters. The amount of sorption at time t, q_t (mg/g), was calculated using the following formula:

$$q_t = \frac{(C_0 - C_t)V}{(W)} \quad (1)$$

where C_t (mgL⁻¹) is the liquid phase concentrations of dye at any time, C_0 (mgL⁻¹) is the initial concentration of the dye in solution.. V is the volume of the solution (L) and W is the mass of dry adsorbent (g).

The amount of equilibrium adsorption, q_e (mg/g), was calculated using the formula

$$q_e = \frac{(C_0 - C_e)V}{(W)} \quad (2)$$

where C_0 and C_e (mgL⁻¹) are the liquid-phase concentrations of dye initially and at equilibrium.

The dye removal percentage can be calculated as follows:

$$(\%) \text{ of dye removal} = \frac{(C_0 - C_e)}{(C_0)} \times 100 \quad (3)$$

where C_0 and C_e (mgL⁻¹) are the initial and equilibrium concentrations of the dye in solution.

To understand the adsorption mechanism, it is necessary to determine the point of zero charge of the adsorbent. The pH at the point of zero charge (pH_{ZPC}) of perlite was measured using the pH drift method

[34-36]. The *pH* of a solution of 0.01 M NaCl was adjusted to between 2 and 12 by adding either HCl or NaOH. Nitrogen was bubbled through the solution at 25°C to remove dissolved carbon dioxide until the initial *pH* stabilized. Adsorbent (0.15 g) was added to 50 ml of the solution. After the *pH* stabilized (typically after 24 h), the final *pH* was recorded. The graphs of final versus initial *pH* were used to determine the points at which the initial and final *pH* values were equal. As shown in **Fig. 1**, this point was taken as pH_{zpc} . In this study, pH_{zpc} of perlite was found to be 8.2.

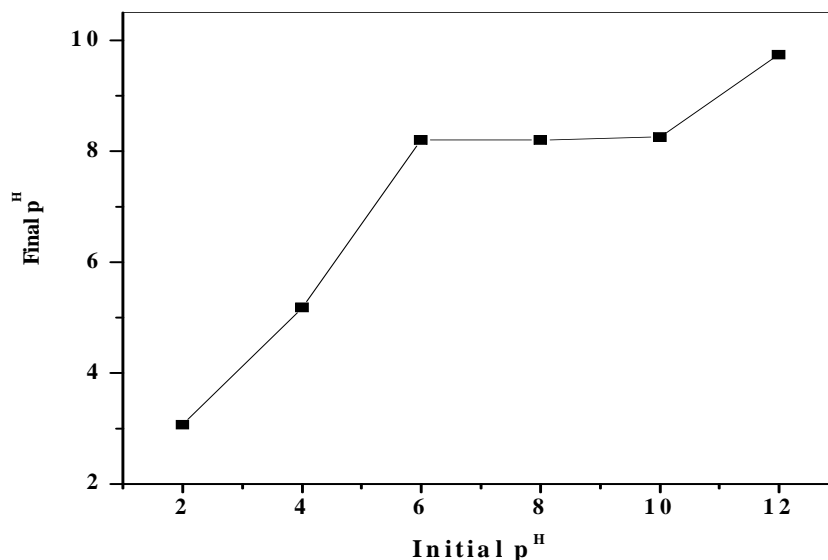


Figure. 1 : Zero point charge (pH_{zpc}) of the used pressure during the adsorption experiment

3. Results and Discussion

3.1 Effect of Adsorbent Quantity

The results for the dye uptake using various amounts of perlite (0.05-1.0 g/50ml) are shown in the Figure 2. The equilibrium dye uptake capacity (q_e) was found to decrease with an increase in the dosage of the adsorbent, and was best when using 0.05 g perlite. Thus, 0.05 g of perlite was selected as the optimum adsorbent dosage. The decrease in dye uptake value (mg dye/g of perlite) was due to the splitting effect of the flux (concentration gradient) between the adsorbate and adsorbent given by Nandi et al., [37].

3.2 Effect of pH

The effect of initial solution pH on the adsorption capacity at equilibrium conditions is shown in **Figure 3**. The results indicate that the dye uptake capacity increased from 166.8 mg/g to 363.4 mg/g with an increase in the value of pH from 2 to 9. The pH of the solution increased further, from 9 to 13, the dye uptake capacity was increased from 363.4 mg/g to 368.6 mg/g. This behaviour can be explained by the zero point charge of the adsorbent ($pH_{zpc} = 8.2$). At a pH above this zero point charge, the surface of the adsorbent becomes negatively charged, which enhances the adsorption of positively charged dye cations (Rhodamine-B) through the electrostatic force of attraction. The maximum adsorption at pH 8-9 may be due to the development of negative charge on the surface of the perlite [38]. On the comparison of Rhodamine-B dye uptake capacity of perlite with other adsorbents [39-41] used, the perlite is a good adsorbent and it remove very high quantity of dye was found in this investigation.

3.3. Effect of contact time and initial dye concentration

The variation in the adsorption capacity (q_t) with contact time given different initial concentrations ranging from 20 to 100 mg/L is shown in **Fig. 4**. Dye uptake was rapid for the first 30 min, and then proceeded at a slower rate and finally attained equilibrium after which the amount of dye adsorbed was negligible. The amount of Rhodamine-B adsorbed per unit mass of perlite at equilibrium, i.e. the equilibrium adsorption capacity of perlite (q_e), increased with increasing initial dye concentrations.

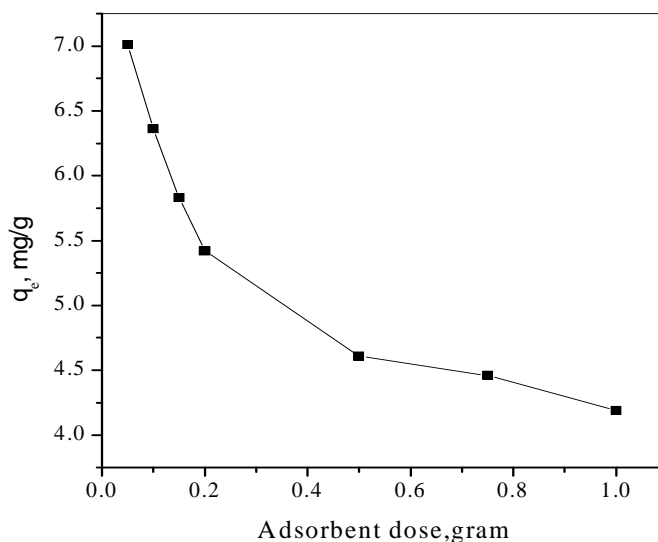


Figure 2: Effect of adsorbent dose on the removal of Rhodamine-B

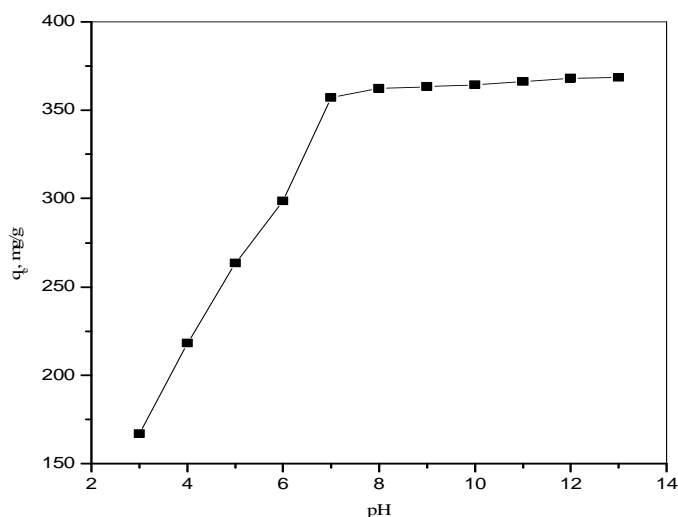


Figure 3: Effect of pH on adsorption capacity of perlite for Rhodamine-B

As the initial concentration of dye increased from 40 mg/L to 100 mg/L, the equilibrium adsorption capacity of dye onto perlite increased from 8.515 mg/g to 37.26 mg/g. This indicates that the initial concentration strongly affects adsorption capacity.

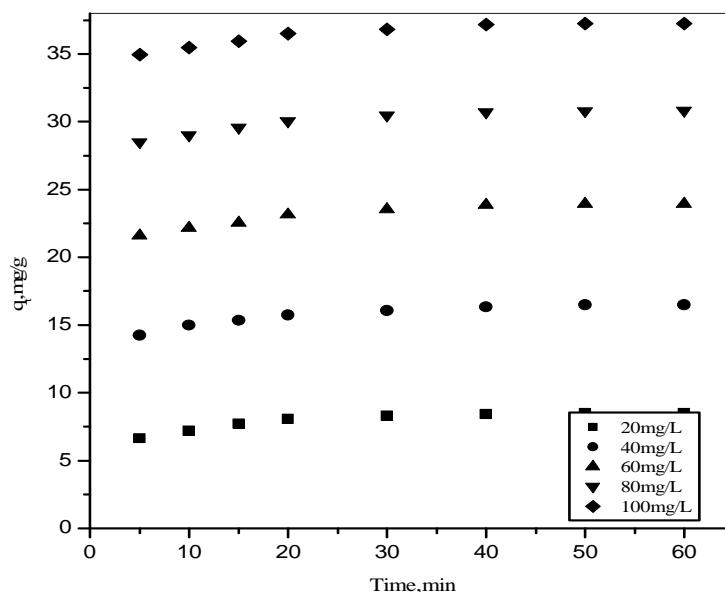


Figure 4: Effect of initial dye concentration and time

3.4. Effect of temperature

To observe the effect of temperature, adsorption studies of Rhodamine B onto perlite were performed at three different temperatures: 30, 40, and 50 °C. The results indicate that when the temperature increased from 30^o C to 50^o C, the adsorption capacity of Rhodamine-B onto perlite increased from 16.48 mg/g to 17.0 mg/g. Therefore, higher temperature facilitated the adsorption of Rhodamine-B on perlite. Thermodynamic parameters such as the free energy change (ΔG), enthalpy change (ΔH) and entropy change (ΔS), were calculated from the variation of the thermodynamic equilibrium constant, K_0 , with temperature. The values of K_0 and other thermodynamic parameters for the adsorption process were calculated using reported methods [29], and the values of ΔH , ΔG , and ΔS for initial concentrations of 20, 40, 60, 80, and 100 mgL⁻¹ are shown in the **Table 1**. The negative values of ΔG indicate the feasibility and spontaneous nature of Rhodamine-B sorption onto perlite. The magnitude of ΔG , increased with increasing temperature, revealing that the degree of spontaneity increased at higher temperatures. The positive values of ΔS reflect an increased degree of disorderliness at the solid/liquid interface during the adsorption of Rhodamine-B onto perlite. The exothermic nature of dye sorption by perlite was confirmed by the negative values of ΔH . The enthalpy value for a sorption process may be used to distinguish between chemical and physical sorption. For chemical sorption, values of enthalpy change range from 83 to 830 kJ mol⁻¹, while for physical sorption they range from 8 to 25 kJ mol⁻¹. The low values of ΔH give clear evidence that the interaction between Rhodamine-B and perlite was weak. On this basis we concluded that dye sorption by perlite is a physical adsorption process.

3.5. Adsorption isotherms

There are several isotherm equations available for analyzing experimental sorption equilibrium parameters, the most common being the Langmuir and Freundlich models. The Langmuir isotherm model is based on the assumption that there is a finite number of active sites which are homogeneously distributed over the surface of the adsorbent. These active sites have the same affinity for adsorption of a mono molecular layer and there is no interaction between adsorbed molecules [43].

A well known linear form of the Langmuir equation can be expressed as

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{q_m b} \quad (4)$$

where q_e is the amount of dye adsorbed (mg/g), C_e is the equilibrium concentration of the adsorbate (mgL⁻¹), and q_m and b_L are Langmuir constants related to the maximum adsorption capacity (mg/g) and energy of adsorption (L/mg).

According to Equation 4, when the adsorption obeys the Langmuir equation, a plot of C_e/q_e versus C_e should be a straight line with a slope of $1/q_m$ and intercept $1/q_m b$ [31]. This important characteristic of the Langmuir isotherm can be expressed in terms of a dimensionless factor, R_L [44], which is defined as

$$R_L = \frac{1}{(1 + b_L \cdot C_0)} \quad (5)$$

The R_L values indicate the type of adsorption as either unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), or irreversible ($R_L = 0$).

Table 1: Equilibrium constant and thermodynamic parameters for the adsorption of Rhodamine-B onto perlite

[C ₀] mg/L	K _o			ΔG ⁰ (KJ/ mol)			ΔH ⁰ (KJ/ mol)	ΔS ⁰ (JK ⁻¹ mol ⁻¹)
	30 ⁰ C	40 ⁰ C	50 ⁰ C	30 ⁰ C	40 ⁰ C	50 ⁰ C		
20	5.711	6.905	8.662	-4.3895	-5.0283	-5.7976	-16.9436	70.335
40	4.674	5.061	5.525	-3.8844	-4.2955	-4.5903	-6.788	35.204
60	3.926	4.111	4.314	-3.4453	-3.6786	-3.926	-3.8221	23.981
80	3.357	3.467	3.582	-3.051	-3.2352	-3.4263	-2.6431	18.787
100	2.925	2.998	3.068	-2.7035	-2.8575	-3.0107	-1.953	15.368

The Freundlich isotherm model applies to adsorption on heterogeneous surfaces with interaction between the adsorbed molecules, and is not restricted to the formation of a monolayer. This model assumes that as the adsorbate concentration increases, the concentration of adsorbate on the adsorbent surface also increases and, correspondingly, the sorption energy exponentially decreases on completion of the sorption centres of the adsorbent. The well-known expression for the Freundlich model is given as [45]

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (6)$$

where q_e is the amount adsorbed at equilibrium (mg/g), K_f is the Freundlich constant, $1/n$ is the heterogeneity factor which is related to the capacity and intensity of the adsorption, and C_e is the equilibrium concentration (mgL⁻¹). The values of K_f and $1/n$ can be obtained from the slope and intercept of the plot of $\log q_e$ against $\log C_e$.

The Langmuir and Freundlich isotherms for the Rhodamine-B-perlite system at different temperatures are shown in **Figs. 5 and 6**. The correlation coefficients were calculated by fitting the experimental equilibrium data for the Rhodamine-B-perlite system using both Langmuir and Freundlich isotherms, and are presented in **Table 2**. These results clearly show that the adsorption of Rhodamine dye on perlite fits well with the Freundlich model. The fact that the Freundlich model is a good fit to the experimental adsorption data suggests physical adsorption as well as a heterogeneous distribution of active sites on the perlite surface.

The observed correlation coefficients for Freundlich isotherms were 0.9984, 0.9994, and 0.9999 at 30, 40, and 50°C, respectively. The other Freundlich constant, n , is a measure of the deviation of the adsorption from linearity. If the value of n is equal to unity, the adsorption is linear. If the value of n is below unity, it implies that the adsorption process is unfavourable, and if the value of n is above unity, adsorption is favourable [33]. In the present study, the value of n at equilibrium was above unity, suggesting favourable adsorption. Furthermore, the values of the dimensionless factor, R_L , were between 0 and 1. This also suggested a favourable adsorption between perlite and Rhodamine-B.

3.6. Kinetic studies

Several kinetic models have been applied to examine the controlling mechanism of dye adsorption from aqueous solution. In this study pseudo-first-order, pseudo-second-order, and intra-particle diffusion were applied. Lagergren's first order rate equation is the earliest known to describe the adsorption rate based on adsorption capacity. The linear form of Lagergren's first order rate equation is as follows [47]:

$$\ln(q_e - q_t) = \ln q_e - K_1 t \quad (7)$$

where q_e is the amount of dye adsorbed onto the adsorbent at equilibrium (mg/g), q_t is the amount of dye adsorbed onto the adsorbent at any time t (mg/g), and K_1 (min^{-1}) is the rate constant of the

Table 2 : Langmuir and Freundlich parameters for Rhodamine-B on perlite

Temp °C	Langmuir isotherms				Freundlich isotherms				R_L (for 20mg/L)
	statistical parameters/constants				Statistical parameters/constants				
	R^2	S_d	q_m	b	R^2	S_d	K_f	N	
30	0.9967	0.0123	67.935	0.0461	0.9984	0.0167	4.1405	1.4506	0.9156
40	0.9907	0.0231	60.976	0.0598	0.9994	0.0099	4.9138	1.5666	0.8932
50	0.9845	0.0332	55.309	0.0783	0.9999	0.0034	5.8979	1.7187	0.8646

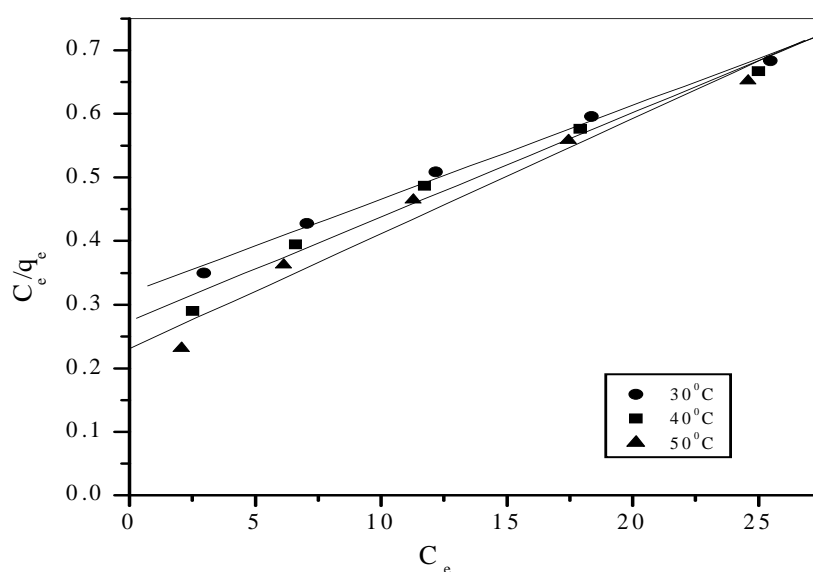


Figure 5: Langmuir isotherms for the adsorption of Rhodamine-B onto Perlite.

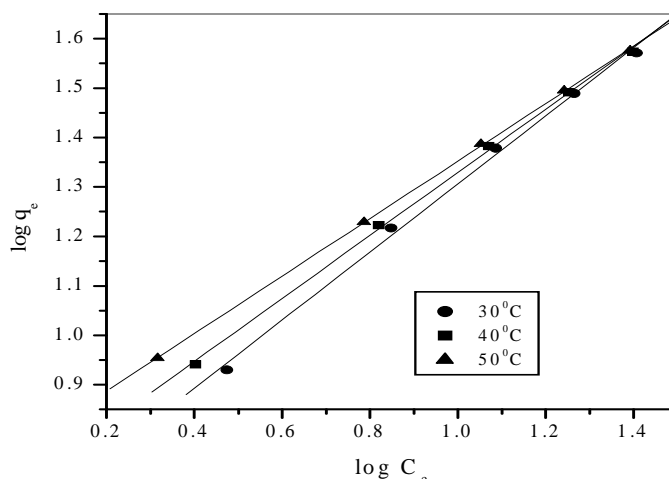


Figure 6: Freundlich isotherms for the adsorption of Rhodamine-B onto perlite

pseudo-first-order adsorption which can be calculated from the slope of the linear plot of $\ln(q_e - q_t)$ vs. t (slope = K_1 , $q_e = \text{exp intercept}$)

Ho [48] proposed a second order model for the sorption of divalent metal ions onto peat particles based on the adsorption capacity of the adsorbents with the goal of differentiating the kinetics of a second-order rate expression based on the adsorbent concentration from models which are based on the solute concentration and represent a pseudo-second-order rate expression.

The linearized form of the pseudo-second-order model as given by Ho [48] is

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (8)$$

where K_2 ($\text{gmg}^{-1}\text{min}^{-1}$) is the rate constant of the pseudo-second-order adsorption, q_e is the amount of dye adsorbed on the adsorbent at equilibrium (mg/g), and q_t is the amount of dye adsorbed on the adsorbent at any time, t (mg/g). K_2 ($\text{gmg}^{-1}\text{min}^{-1}$) can be calculated from the slope and intercept of the plot of t/q_t against t .

The intra-particle diffusion equation [49] can be written as

$$q_t = K_{ipd} t^{1/2} + C \quad (9)$$

where q_t is the amount of dye adsorbed onto the adsorbent at time t (mg/g), C is the intercept, and K_{ipd} is the intra-particle diffusion rate constant ($\text{mg g}^{-1} \text{min}^{-1}$).

The straight line plots of $\log(q_e - q_t)$ against time for the pseudo-first order reaction, and t/q_t against time for the pseudo-second-order reaction of the adsorption of Rhodamine-B onto perlite are shown in **Figs. 7 and 8**. The calculated value of k_1 , k_2 , q_e and their corresponding regression coefficient values (R^2) are presented in Table 3. The correlation coefficients are closer to unity for pseudo-second-order kinetics than for pseudo-first order kinetics. This suggests that the adsorption system can be better represented by the pseudo-second-order model. The plot of q_t vs $t^{1/2}$ for intra-particle diffusion in the adsorption of Rhodamine-B onto perlite at various temperatures (not shown) was used to obtain the diffusion rate parameters. The intra-particle diffusion plot is curved in the small time limit, which might be due to a mass transfer effect. There are two separate regions in the curves. The initial curved portion reflects the film or boundary layer diffusion effect, and the linear portion represents the intra-particle diffusion effect. The correlation coefficients for intra-particle diffusion ($R^2 = 0.96-0.98$) were lower than for the pseudo-second order kinetics. This indicates the

present system may be followed by intra-particle diffusion. Furthermore, the plots don't pass through the origin, an observation that suggests some degree of boundary layer control.

Table 3: Pseudo-first-order, Pseudo-second-order and Intra-particle diffusion values

C_0 (mgL^{-1})	Pseudo I Order				Pseudo II Order			Intra-particle	
	Experimental		Calculated		Calculated			Calculated	
	q_e	K_1	q_e	R^2	K_2	q_e	R^2	R^2	K_{ipd}
20	8.72	0.0869	2.862	-0.9972	0.0592	8.809	0.9999	0.9627	0.3955
40	16.7	0.0725	3.234	-0.9956	0.0482	16.818	0.9999	0.9833	0.3785
60	23.91	0.0932	4.634	-0.9852	0.0448	24.307	0.9999	0.9735	0.3785
80	30.82	0.0872	4.179	-0.9958	0.0468	32.787	0.9999	-----	-----
100	37.26	0.0862	4.263	-0.9841	0.0463	37.636	0.9999	-----	-----

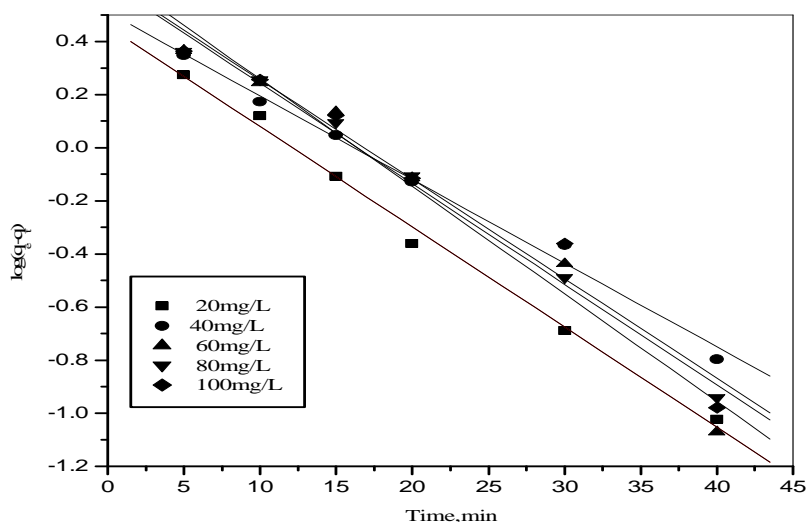


Figure 7: Pseudo first order kinetic plot for the adsorption of Rhodamine-B onto perlite.

3.7. Fourier transform infrared spectroscopy (FT-IR) investigation.

The FT-IR spectra images of perlite and loaded Rhodamine-B were recorded and are shown in **Fig. 9**. In the FT-IR spectra of perlite, the peak at 3375 cm^{-1} might be due to the presence of uncondensed -OH groups. The peak at 930 cm^{-1} is due to Si-O stretching vibrations in the Si-OH bond. The asymmetric stretching vibrations of Si-O-Si bridges were observed at 1109 cm^{-1} . The peak at 900 cm^{-1} indicates the presence of Si-O-Al bonds [50]. Slight reductions in the peaks at 3375 cm^{-1} and 930 cm^{-1} were seen, but the peak positions did not change. This clearly indicates the adsorption of dye on the adsorbent by physical forces instead of chemical combination.

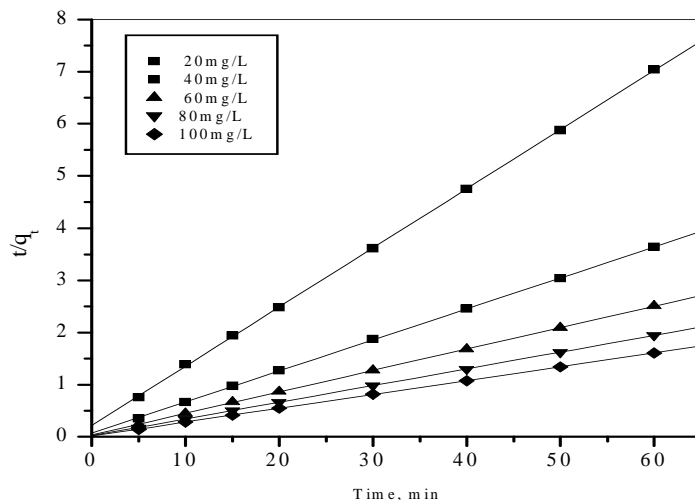


Figure 8: Pseudo second order kinetic plot for the adsorption of Rhodamine-B onto perlite.

3.8. Scanning Electron Microscopic (SEM) studies.

The SEM images of perlite and loaded Rhodamine-B were recorded and are shown in **Fig. 10**. In the SEM micrograph 10(a), the bright spots show the rough and porous surface of the adsorbent, which is one of the factors increasing adsorption capacity. The loaded SEM images show the adsorption of Rhodamine-B on the perlite. In Fig. 10(b) depicting the surfaces of particles after adsorption, it is clearly seen that the caves, pores and surfaces of adsorbent were covered by dye and consequently the surface has become smooth. It is evident that upon adsorbing the Rhodamine-B the adsorbent structure has changed.

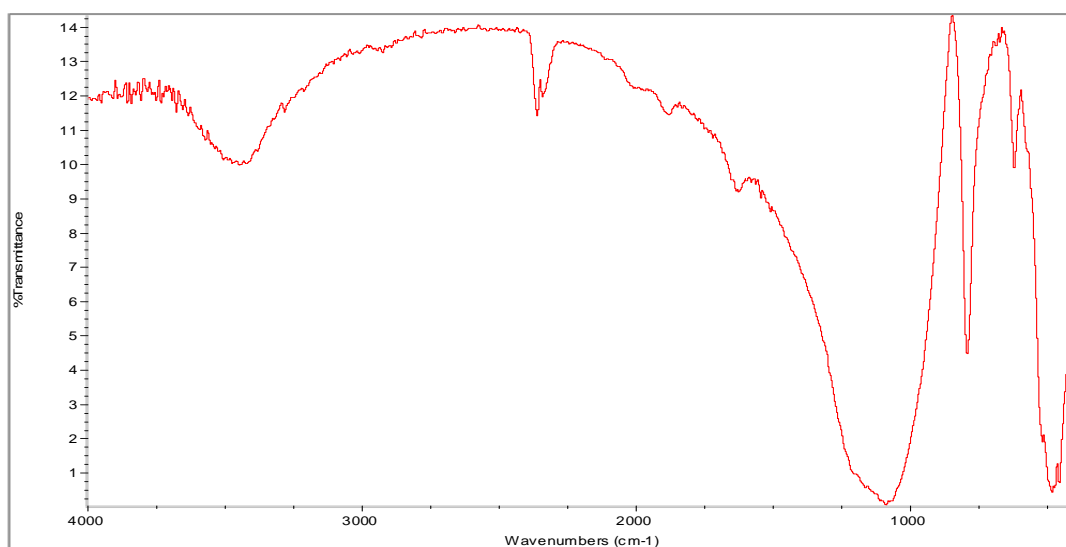


Figure 9: (a) FT-IR spectrum of the adsorbent perlite before the adsorption.

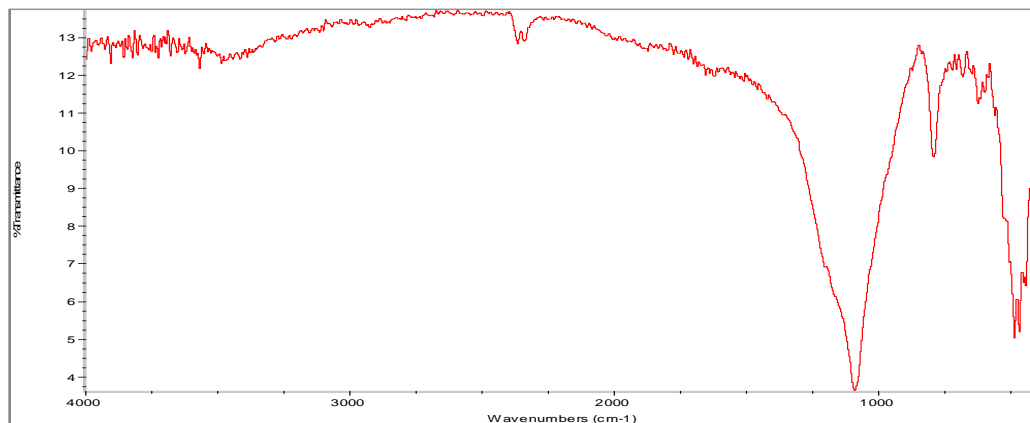


Figure 9: (b) FT-IR spectrum of the adsorbent perlite after the adsorption.

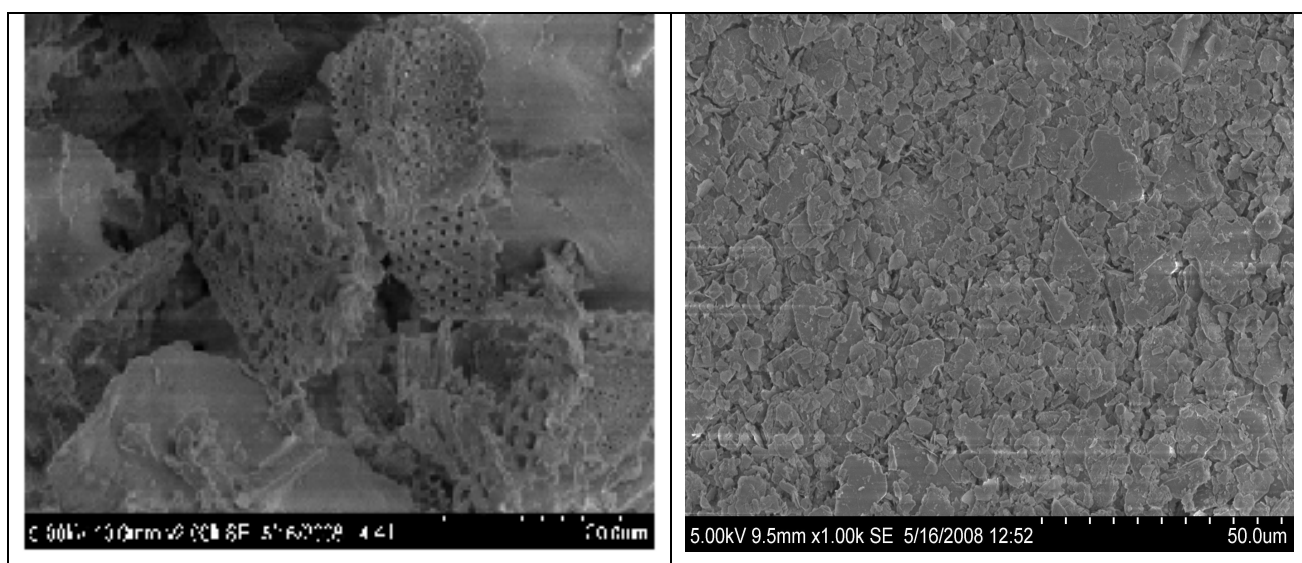


Figure 10: (a) SEM image of the perlite before the adsorption

Figure 10: (b) SEM image of the adsorbent perlite after the adsorption

Symbols

Subscripts

b	Constant related to the affinity of the binding sites	[L/mg]
C_0	Liquid-phase concentrations of dye at initial	[mg/L]
C_e	Liquid-phase concentrations of dye at equilibrium	[mg/L]
C_t	Liquid-phase concentrations of dye at any time	[mg/L]
ΔG	Standard Gibbs free energy change	[KJ/mol]
ΔH	Enthalpy change	[KJ/mol]
K_F	Freundlich constant	[mg/g]
K_1	Pseudo-first-order rate constant	[(min ⁻¹)]
K_2	Pseudo-second-order rate constant	[g/mg min]
K_{ipd}	Intraparticle diffusion rate constant	[mg/g min ^{1/2}]
n	Dimensionless exponent of Freundlich equation	
q_t	Amount of biosorption at time t	[mg/g]
q_e	Amount of adsorbed dye per unit mass of sorbent [mg/g]	
q_m	Maximum amount of the adsorbed dye per unit mass of Sorbent	[mg/g]
R_L	Dimensionless constant separation factor	
ΔS	Entropy change	[kJ/mol·K]

Conclusion

This study investigated the adsorption of a basic dye, Rhodamine-B, onto perlite as a function of adsorbent dose, initial dye concentration, pH, and temperature. We found (1) that the adsorption equilibrium correlated reasonably well with the Freundlich isotherm, (2) the adsorption kinetics of Rhodamine-B onto perlite, (3) thermodynamic results which indicate that adsorption of Rhodamine-B onto perlite is spontaneous and physical in nature, and (4) a positive value for the adsorption entropy which indicates that adsorbed dye molecules remain randomly on the perlite surface. Finally, by evaluating the values of ΔH_{ads} , ΔS_{ads} , and ΔG_{ads} , we concluded that perlite has considerable potential as an adsorbent for the removal of Rhodamine-B.

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