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REMOVAL OF RHODAMINE-B DYE USING CHEMICALLY MODIFIED ACTIVATED MUSCOVITE: KINETICS, ISOTHERMS, AND THERMODYNAMIC STUDIES

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ABSTRACT

The chemically modified Muscovite adsorbent was prepared by activation of Muscovite with HCl and H_2O_2, and used for the adsorption of Rhodamine-B dye removal (RB) from polluted water. Optimum conditions were applied for maximum RB dye adsorption (solution temperature, adsorbent dose, pH, stirring time, and initial dye concentration). The results show that the maximum adsorption of RB dye (21.22 mg g^{-1}) was achieved using a Muscovite adsorbent prepared with a mixture of HCl /H_2O_2. The maximum adsorption of RB dye by activated Muscovite adsorbent was 88.2 % at initial RB concentration 50 ppm, 60 min contact time, 25°C, adsorbent dose 1 g 50 mL^{-1}, and pH 4. The adsorption kinetics studies show that the RB adsorption follows the pseudo-second-order kinetic model. Adsorption isotherm models were investigated and ended to that the adsorption of RB dye by the activated Muscovite fitted well Langmuir adsorption isotherm. The thermodynamics parameters of RB dye adsorption using activated Muscovite indicated spontaneous and endothermic processes.

Keywords: *adsorption, Muscovite, acid activation, purification, Rhodamine-B dye.*

INTRODUCTION

Organic pollution of rivers by industrial wastewater discharge negatively impacts the water and its organisms and so affects human health. One of these organic pollutants in the river is dyes. Dyes as highly toxic organic compounds used in various industries (plastics, textile, leather, rubber, and paper) and cause serious environmental impacts when disposed to the water body. Industries release about 100 tons of dyes into the rivers per year [1, 2], 5 - 10 % of these dyes are lost in industrial wastewater [3]. It is difficult to remove the dyes from water, as they have a very complex molecular structure difficult to degrade [4]. There are several dye classes such as acidic, reactive, vat, azo, basic, direct, sulfur, and mordant dyes [5, 7]. The acidic dyes are highly soluble in water [8], while basic dyes are the brightest class of soluble dyes [9].

Industrial wastewater, containing dyes can be treated by chemical and physical methods such as adsorption, photochemical degradation, sonochemical degradation, electrochemical degradation, membrane separation, coagulation, flocculation, and oxidation or ozonation [10 - 14]. Most research has attracted great interest in the application of low-cost adsorbents for the removal and treatment of dye from industrial wastewater [15]. In addition to its use in the dyeing of various products, Rhodamine B dye is used also as biological stains [9].

Clay is a class of materials consisting of layered clay minerals or silicates and traces of organic matter and metal oxides. It has large surface areas and is abundant and widespread in terrestrial and aquatic environments [16]. Muscovite, $KAl_2[Si_3AlO_{10}(OH)_2]$, is a hydrated magnesium aluminum silicate mineral that belongs to the mica group and has different applications regarding its low-cost, high availability and selectivity as well as easy handling [17]. Mica group minerals consist of octahedral [$Al(O/OH)_6$-sheet] layers sandwiched by two tetrahedral

SiO_4-sheets [18]. Rashed et al. studied cadmium and lead adsorption on the modified Muscovite, and found that the Muscovite adsorbent prepared with a mixture of HCl /H_2O_2 shows higher adsorption of Cd and Pb than that with HCl or H_2O_2 [10].

Ganguli et al. studied RB dye adsorption from an aqueous solution using natural kaolinitie. Optimum adsorption experiments were carried out by varying initial dye concentration, contact time, pH, adsorbent dosage, and temperature [19]. The equilibrium data were well fitted by both the Freundlich and Langmuir adsorption isotherms. Hou et al. studied RB dye removal using Fe-Ben adsorbent and found that pH 5.0 was the most favorable for RhB adsorption [20]. Bhattacharyya et al. studied the removal of RB dye using treated montmorillonite and kaolinite [21]. Duarte et al. found that the highest removal of RB dye onto purified bentonite was at pH 3 [22]. Santos et al. reported that the adsorption of RB using calcined bentonite clay was favored using adsorbent dosage 500 mg L^{-1}, pH 3, and a temperature 35°C [23]. Rao et al. studied the adsorption of RB dye on some types of clay minerals and found that the ionic strengths, solution pH, and temperature influence RB uptake [24]. Khan et al. studied the adsorption efficiency of RB on kaolinite, and found the optimized conditions for adsorption: 90 mgL^{-1} initial RB concentration, 80 min agitation time, 3 gL^{-1} adsorbent dose, pH 7, and 303 K temperature [25].

The purpose of this research is to prepare low-cost and eco-friendly adsorbents from Muscovite by activation with H_2O_2/HCl, and use it for the adsorption of Rhodamine-dye from polluted water.

EXPERIMENTAL

Chemicals and Reagents

All chemicals used were of analytical grade. The stock solution of Rhodamine-B (1000 ppm) is prepared by dissolving 1 g of RB dye in 1000 mL of distilled water. The standard calibration curve of RB dye was plotted at wavelength 558 nm using spectrophotometer. RB is a basic red cationic dye (Fig. 1). It is mainly used in cotton, textile, wool, silk, and food industries. This dye is harmful to humans in which it can cause irritation to the skin, gastrointestinal eye burn, and respiratory tracts. So, the treatment of the RB dye effluents is essential prior to their discharge into the water [26].

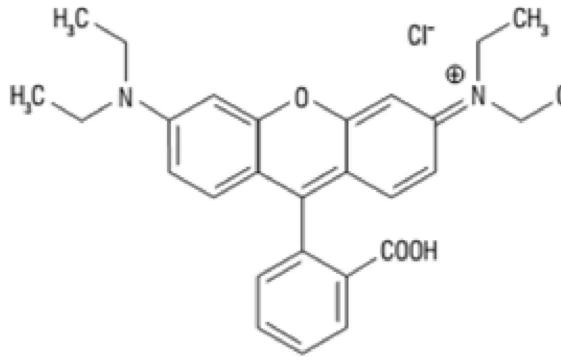

Fig. 1. Chemical structure of Rhodamine B dye.

Table 1. Chemical and Physical Properties of Rhodamine B.

Chemical formula	$C_{28}H_{31}ClN_2O_3$
Molar mass	479.02
Appearance	red to violet powder
Melting point	210 to 211°C (410 to 412°F; 483 to 484 K)
Solubility in water	~15 g L^{-1} (20°C)

Sample collection

Muscovite clay was collected from the Hafafit area (south of the east desert, Egypt). Five bulk samples (5 kg) were collected from the area. The sample was crushed, ground to powder to 65 µm, and dried at 60°C for 24 h. The chemical composition of the Muscovite sample was detected by XRF as SiO_2 48.16 %, Na_2O 0.72 %, K_2O 10.62 %, Al_2O_3 32.5 %, Cd 12.70 ppm, and Zn0.482 ppm

Preparation of Muscovite adsorbent

Purification of Muscovite

As in our previous work, 10 g Muscovite was sonicated in 100 mL deionized water for 10 min, let stand down for 10 min, separated by decantation, filtered the solution, and dried in 60°C for 24 h [10]. This step was repeated twice.

Chemical activation of Muscovite

Chemically activated muscovite was prepared according to our previous work [10]. Activation of the Muscovite was run by mixing the purified powder Muscovite with different concentrations of mixture HCl/H_2O. Purified muscovite (5 g) and 200 mL 0.8 M HCl were stirred at 25°C for 10 h, filtered, washed with distilled water, and dried at 100°C for 10 h. The acid activated Muscovite (5g) was mixed with 30 % H_2O_2, stirred for 7 h, filtered, washed with distilled water till the solution became neutral, dried at 100°C for 10 h, and ground in an agate mortar to 63 µm.

Batch adsorption experiments of Rhodamine-B dye

Batch adsorption experiments were carried out by using 0.2 g activated Muscovite, 50 mL 50 ppm RB dye, 2 h contact time, and pH 4. The mixture was then filtered and the RB dye in the filtrate was measured by spectrophotometer at λ 558 nm.

Adsorption Experiments

Experiments were performed at room temperature 25ºC, with 50 mL 30 ppm RB dye, while pH was maintained naturally. The resulted solution was filtered, and the remaining concentration was measured by a spectrophotometer at λ = 558 nm

The removal percentage of RB dye was calculated by the equation:

$$\% R = [(C_o – C_e) /C_o] *100 \quad (1)$$

q_e (mg g^{-1})(amount of RB dye per unit mass of the adsorbent) was calculated by the following equation

$$q_e = (C_o – C_e / m)v \quad (2)$$

where: C_o = initial RB dye concentration (ppm); C_e = RB dye equilibrium concentration (ppm); V = the volume of RB dye solution (L); m = the mass of adsorbent (g).

Optimal parameters for the maximum adsorption of RB dye on activated Muscovite

Effect of pH

The effect of initial pH was investigated at various pH (2, 3, 4, 5, 6, 7, 8, and 10). 1 g of Muscovite adsorbent was added to 50 mL of the dye solution (initial concentration 30 ppm) and stirred for 120 min. The resulting solution was filtrated through a Goch funnel, and the equilibrium concentration of RB was then measured by a spectrophotometer.

Effect of adsorbent dosage

A 50 mL RB solution (30 ppm) was mixed with various dosages of adsorbent (0.5, 1, 1.5, 2 and 3 g) at a contact time of 120 min, temperature 25ºC, and pH 4. The RB concentration was measured by spectrophotometer in the filtrate.

Effect of initial dye concentration

2 g of adsorbent was mixed with 50 mL of different RB concentrations (5, 10, 20, 30, 50, 75, and 100 ppm), keeping other parameters constant (pH 4, contact time 120 min, and temperature 25ºC). The mixture was agitated and filtered through a Goch funnel, and then the RB concentrations were measured using a spectrophotometer.

Effect of contact time on adsorption

2 g of adsorbent was added to 50 mL of 30 ppm RB dye solution at various contact times (30, 60, 120, 180, 240, and 300 min) keeping other parameters constant (pH 4.0 and temperature 25ºC). After the specified time, the solution was filtered through a Goch funnel and the equilibrium RB concentration was measured by a spectrophotometer.

Effect of temperature

2g of adsorbent was added to a 50 mL of 30 ppm dye solution. The experiments were carried out at 25, 35, 45, and 55ºC for 60 min, with contact time at pH 4.0. After filtration, the concentration of dye was measured.

Adsorption isotherms

Batch experiment was studied by mixing activated Muscovite (2g) with 50 mL dye solution (30 ppm) and agitated at 250 rpm for 60 min. The RB dye concentration was measured using a Shimadzu UV-1601PC UV-Vis spectrophotometer at wavelength 555 nm.

Langmuir isotherm

The Langmuir model indicates monolayer adsorption. The Langmuir equation is described by the equation:

$$C_e/q_e = 1/Q_o b + C_e/Q_o \quad (3)$$

where C_e, (ppm) the equilibrium concentration of dye solution, Q_o (mg/g) the monolayer adsorption capacity of the adsorbent, q_e (mg g^{-1}) is the equilibrium capacity of dye on the adsorbent, and b (L/mg) is the Langmuir bonding energy coefficient.

The Q_o and b values can obtain from the slope and intercept of the plot of C_e/q_e vs C_e.

Freundlich isotherm

The Freundlich equation determines the applicability of heterogeneous surface energy. The Freundlich equation is:

$Log\ q_e = \log K_f + 1/n \log C_e$ (4)

K_f is the adsorption capacity, and n is the adsorption intensity. When 1/n is below 1 this indicates a normal adsorption, while when above 1 indicates cooperation adsorption. n and K_f values can be obtained from the intercept and slope of plot log q_e vs log C_e.

The Temkin isotherm

The Temkin isotherm model describes a uniform distribution of binding energies over the surface binding adsorption. Temkin equation is:

$q_e = B \ln K + B \ln C_e$ (5)

$B = RT/b$

Temkin constant (b) is the heat of adsorption, q_e (mg/g) is the amount of dye per unit weight of adsorbent, and C_e (ppm) is un absorbed dye concentration in solution at equilibrium. From the plot of q_e vs ln C_e the constants B and K were obtained related to the heat of sorption (J/mol), and equilibrium binding, respectively.

Dubinin-Radushkevich isotherm model

Dubinin-Radushkevich isotherm expresses the adsorption mechanism with a Gaussian energy distribution onto a heterogeneous surface [27]. It means that it is applied to distinguish between physical and chemical adsorption of dye.

The linearized D-R equation [28] :

$Ln\ q_e = \ln q_m - BE^2$ (6)

where B (mol/kJ) constant is the adsorption energy, q_m (mg/g) constant is the adsorption degree, and E is the polanyi potential that obtained by the following equation:

$E = RT \ln (1+1/Ce)$ (7)

T is the absolute temperature (K), and R is the ideal gas constant ($R=8.314$ J mol^{-1} K^{-1}) .

From the plot of ln q_e vs E^2, the constants q_m and B can be obtained. The mean free energy E (KJ/mol) of adsorption can be calculated by the following equation [29]:

$E = 1/ (2B)^{½}$ (8)

where E characterize the adsorption type as physical adsorption ($E < 8$ kJ mol^{-1}) , or chemical ion exchange ($E = 8 - 16$ kJ mol^{-1}) [30] .

Kinetic studies

Kinetic models determine the mechanism of the adsorption process. The kinetics of adsorption that defines the efficiency of RB dye on activated Muscovite adsorbent were checked by different kinetic models (Pseudo–first order, Pseudo-second order, Elovich, and Intraparticle diffusion models).

Pseudo-first order model

This model is described as follows:

$Log\ (q_e - q_t) = \log q_e - (K_1/2.303)\ t$ (9)

where, q_e and qt (mg g^{-1}), are the adsorption capacities at equilibrium and at time (min) respectively, and K_1, is the rate constant [31]. K_1 and qe can obtain from the plot of log (q_e-q_t) vs t plot.

Pseudo-second order model

The linear form of this equation is represented as:

$t/q_t = 1/K_2 q_e^2 + 1/q_e t$ (10)

K_2 (g mg^{-1} min^{-1}) is the rate constant.

K_2 and q_e can be calculated from the plot of t/q_t vs t.

Intraparticle diffusion model

This model was used to identify the mechanism of the solute transfer involved in adsorption process and can be expressed by the equation

$q_t = K_i t^{½} + C$ (11)

K_i (mg g^{-1} $min^{-1/2}$), is the rate constant, and C (mg g^{-1}) is the boundary layer effect. The K_i and C can be obtained from a linear plot of q_t vs $t^{1/2}$.

Elovich model

This model is used for describing the activated chemisorption by the equation:

$q_t = 1/\beta \ln[\alpha\beta] + 1/\beta \ln t$ (12)

where α is the initial adsorption, and β, the adsorption coefficient.

Thermodynamics of adsorption

Adsorption thermodynamics was studied at temperatures 298, 313, and 333 K.

The thermodynamic parameters [Gibbs free energy (ΔG^o), entropy (ΔS^o), and enthalpy (ΔH^o)] were calculated by the following equation:

$$\text{Ln } k = \Delta S^o/R - \Delta H^o/RT \quad (13)$$

where R (8.314 J mol^{-1} K^{-1}) is the gas constant and T (K) is the temperature. ΔS^o and ΔH^o were calculated from the plot of Ln k vs. 1/T.

The free energy of specific adsorption ΔG^0 (KJ mol^{-1}) is calculated from the following equation:

$$\Delta G^o = \Delta H^o - T\,\Delta S^o \quad (14)$$

RESULTS AND DISCUSSION

Optimal parameters for the adsorption of Rhodamine B dye on activated Muscovite

Effect of pH on RB adsorption

The effect of pH idirectly influences the electrostatic interaction of the absorption system. The results of the pH effect on RB adsorption (Fig. 2) reveal that the RB removal increased with increasing pH from 2 to 4 (67.8 to 77.2 %), then decreased until pH 10. The highest RB removal was monitored at pH 3 and 4. This could be explained due to the RB molecules exist in cationic and monomeric forms at pH < 4.0. Also, the smaller monomeric RB may diffuse into the micropores of the adsorbent particle more readily than the dinner form [32].

Kooh et al. found that RB dye removal from solution using Casuarina equisetifolia needles as adsorbent was the highest at pH 2.9 [33]. Penga et al. found that the removal of RB on modifying Fe_3O_4 nanoparticles was the highest (98.5 %) at pH 2.53 [34].

Effect of adsorbent dosage on RB dye adsorption

The results (Fig. 3) reveal that with the increase of activated Muscovite adsorbent dosage from 0.2 to 2 g, the removal of RB dye increased from 47.7 % to 77.2 %. This increase is related to the increase in active sites with increasing adsorbent dosage, and also due to higher collision rate between the adsorbent particles, resulting in less vacant sites available for RB adsorption [33]. So, the amount of 2 g Muscovite adsorbent dosage was selected as the optimized adsorbent dosage for the rest of the experiment.

Effect of initial RB concentration on the adsorption

The effect of RB dye concentrations on the adsorption capacity of activated Muscovite is shown in Fig. 4. As RB dye concentration increased from 5 to 30 ppm, its removal percentage increased from 56.1 % to 77.3 %. The active sites on activated Muscovite were enough to accommodate the number of dye molecules, but then became saturated with dye molecules as the dye concentration increased [35]. So, the 30 ppm initial dye concentration was selected as the optimized adsorbent dosage for the rest of the experiment.

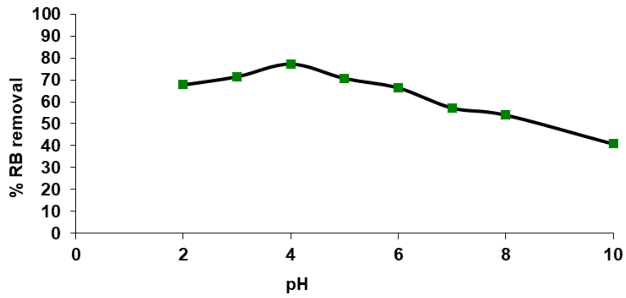

Fig. 2. Removal of RB on activated Muscovite adsorption according to pH.

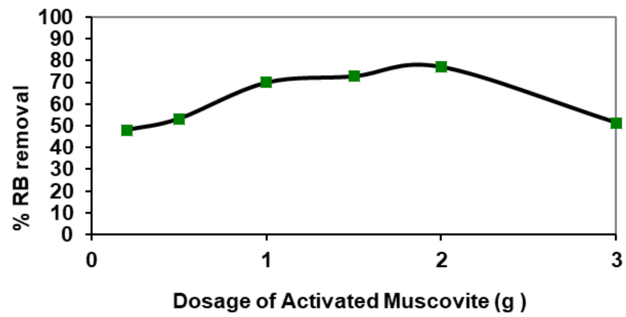

Fig. 3. Removal of RB on activated Muscovite adsorption according to dose.

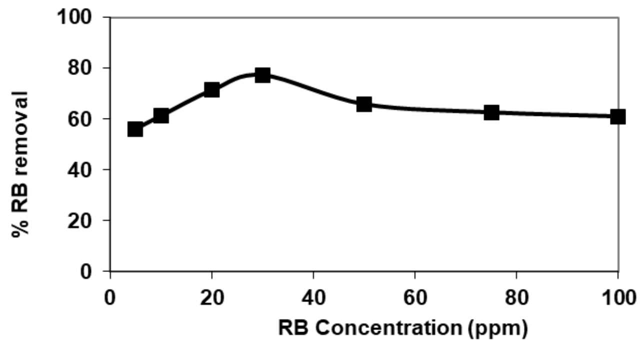

Fig. 4. Removal of RB on activated Muscovite adsorption according to RB initial concentration.

Iryani et al. studied the adsorption of RB dye with the zeolite (ZSM-5) directly synthesized from Bangka

Table 2. Isotherm data for the adsorption of RB dye on activated Muscovite according to initial RB dye concentration at 25^{o}C.

Conc. ppm	% RB adsorbed	C_e	q_e	C_e/q_e	Log C_e	Log q_e	E^2	Ln C_e	Ln q_e	$1/C_e$
5	56.059	2.197	0.070074	31.354	0.342	-1.155	881203.2	0.787	-2.658	0.456
10	61.238	3.876	0.153095	25.319	0.588	-0.815	329880.6	1.355	-1.877	0.258
20	71.327	5.734	0.356637	16.08	0.759	-0.448	161812.5	1.747	-1.031	0.174
30	77.954	6.614	1.584655	11.31	0.820	-0.23	124160.6	1.889	-0.537	0.151
50	65.794	17.10	0.822421	20.796	1.233	-0.085	20221.14	2.839	-0.196	0.059
75	62.555	28.084	1.172908	23.94	1.449	0.069	7666.652	3.335	0.16	0.036
100	60.964	39.036	1.524107	25.61	1.592	0.183	4007.008	3.665	0.42	0.026

Kaolin without an organic template and found that the adsorption remains stable above 100 ppm RB [36].

Effect of contact time on RB dye adsorption

The results of the contact time effect on RB dye adsorption are summarized in Fig. 5. The highest RB dye removal was at 60 min contact time when an equilibrium or quasi-stabilised state was presumed to have been reached. So it was applied for the rest of the experiment.

Iryani et al. reported that the adsorption of RB dye with the zeolite (ZSM-5) directly synthesized from Bangka Kaolin remains stable at 60 min [36].

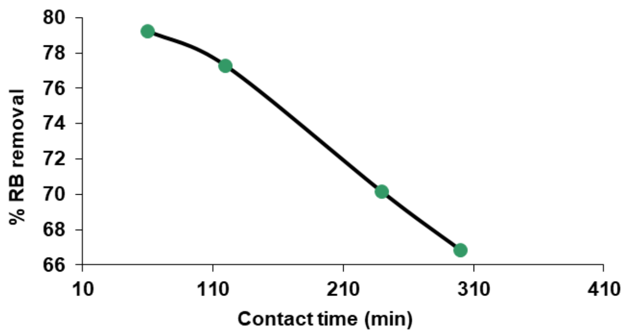

Fig. 5. Effect of contact time on the Removal of RB using activated Muscovite .

Effect of temperature on RB adsorption

The effect of temperature on the adsorption of RB had been studied at different solution temperatures (25, 35, 45, and 60^{o}C). The results were represented in Fig. 6. The results showed that the RB removal on activated Muscovite increased at room temperature (25°C).

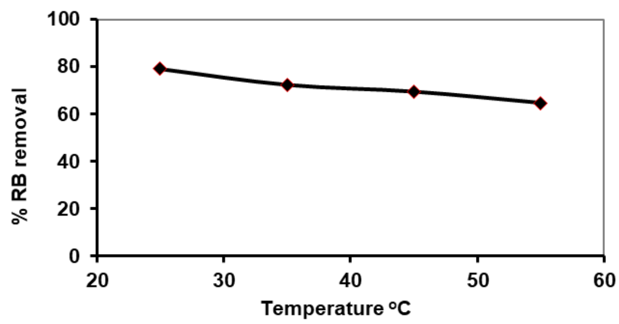

Fig. 6. Removal of RB on activated Muscovite adsorption according to temperature.

Adsorption isotherms

The experimental data are presented in Table 2, and fit into the following isotherms: Freundlich, Langmuir, Dubinin-Raduskevich (D-R), and Temkin isotherm models.

Langmuir isotherm

From equation (3) the b_1 and Q_o can be obtained from the linear plot of C_e/q_e vs C_e. The data are depicted in Table 3. The high regression coefficient (R^2) was 0.969, while the maximum absorption of RB dye on the activated Muscovite (Q_0) was 21.22 mg g^{-1}.

Freundlich isotherm

From equation (4), K_f and n can be calculated from the intercept and slope of the linear plot of log q_e vs log C_e. The data were presented in Table 3. The value of 1/n for RB was 0.2 which indicates effective adsorption; it also indicated the degree of variability of adsorption. From the results, it was observed that the value of K_f for RB dye was 23.4 ($mg^{-1/n}$ $L^{1/n}$ g^{-1}).

Table 3. Results of isotherm plot parameters for adsorption of RB dye.

Parameters	RB dye
Langmuir Isotherm model	
Q_0 (mg/g)	21.22
b_L (L/mg)	0.054
R^2	0.969
Freundlich Isotherm model	
1/n	0.2
K_f ($mg^{-1/n}$ $L^{1/n}$ g^{-1})	23.4
R^2	0.91
Temkin Isotherm model	
B (j/mol)	4.46
b_T	555.5
Kt (L/g)	138.3
R^2	0.95
Dubin-Raduskevich Isotherm model	
q_D (mg/g)	15.8
E (kj/mol)	0.5
R^2	0.88
β (mol^2/kJ^2)	$2*10^{-6}$

Temkin isotherm

The values of B and K are given in Table 3. B values for RB dye is 4.46. The lower B values of RB indicate that RB has lower heat of adsorption.

Dubinin-Radushkevich (D-R) isotherm model

D-R isotherm is applied to express the adsorption mechanism with the distribution of Gaussian energy onto a heterogeneous surface [27]. It means that it is applied to distinguish between the physical and chemical adsorption of heavy metals.

The values of β and q_m (from equation (8)) are given in Table 3.

The adsorption of RB dye on activated Muscovite fitted Langmiur isotherm due to the high correlation factor (R^2) than the other isotherm models.

Adsorption kinetic studies

Kinetic models describe the mechanism of the adsorption process which is useful to improve the adsorption efficiency [37]. The kinetics of RB dye adsorption on activated Muscovite was checked by the pseudo-first order, pseudo-second order, Elovich model, and Intraparticle diffusion. The kinetic data of the adsorption of RB dye on activated Muscovite are presented in Tables 4.

Pseudo-first order model

The adsorption kinetic parameter and the correlation coefficient for adsorption of RB dye on activated Muscovite are derived from equation (8) and presented in Table 5. The result shows that K_1 (min^{-1}) for RB dye is 0.09, and the correlation coefficient (R^2) is 0.895.

Pseudo-second order model

The data in Table 5 show that the equilibrium adsorption capacity (q_e) is 16.23 mg g^{-1}. The difference between q_e calculated and q_e experimental seems to be close, and so the RB dye removal with activated Muscovite is described by the second order reaction kinetics. Also, the correlation coefficient (R^2) of second-order reaction kinetics is higher than R^2 of the first-order reaction kinetics.

Table 4. Parameters of the effect of contact time and initial dye concentration (30 ppm) on the RB dye adsorption of on activated Muscovite at 25°C.

Time (t) min	RB Removal%	C_e	q_t	$q_e - q_t$	Log ($q_e - q_t$)	t/q_t	Ln t	$t^{1/2}$
60	79.24	2.28	0.168	15.61	1.208	86.57	4.10	7.75
120	77.68	2.54	0.176	15.6	1.208	174.75	4.79	10.95
240	70.15	2.99	0.187	15.63	1.207	355.36	5.48	15.49
300	66.87	3.32	0.194	15.63	1.207	449.67	5.71	17.32

Intra-particle diffusion model

Intra-particle diffusion data is represented in Fig. 7 and Table 5. The data showed that the C (the boundary layer effect) is 2.145 mg g^{-1}. From this result, the first line represented rapid transfer and fast uptake of RB dye onto the adsorbent surface by physical forces. In the second stage, the adsorption speeds up of RB dye reflecting nonconsecutive diffusion of RB dye molecules into the micropores.

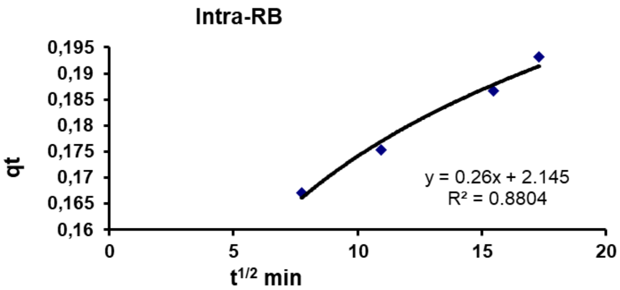

Fig. 7. The intra-particle kinetic for the adsorption of RB.

Elovich model

The parameters of the Elovich kinetic model, [α], [β], and R^2, are calculated and tabulated in Table (5).

In conclusion, the data of the four kinetic models (Table 5) improve that the adsorption of RB dye on activated Muscovite follows pseudo second-order kinetic.

Table 5. Calculated kinetic parameters for the adsorption of RB dye.

Parameters	RB dye
Pseudo first-order	
K_1 $(min)^{-1}$	0.09
q_e (mg/g)	15.84
R^2	0.895
Pseudo second-order	
K_2 (g/mg min)	$4.8*10^{-4}$
q_e (mg/g) calculated	1.623
q_e (mg/g) experimental	1.58
R^2	0.9983
Elovich model	
α (mg/min)	8.24
β (g/mg)	0.65
R^2	0.847
Intra particle diffusion model	
K_{id}	0.26
C (mg g^{-1})	2.145
R^2	0.88

Thermodynamics of adsorption

The estimated thermodynamic parameters ΔH° and ΔS° and ΔG° are presented in Table 6. The ΔG° was found to be −2.64, −3.94, − 5.24 and −6.54 kJ/ mol at temperatures 25, 35, 45, and 55°C, respectively. The ΔG° with increasing temperature becomes less positive that proving the spontaneity of activated Muscovite–RB adsorption. The positive value of ΔH° indicates that Activated Muscovite –RB adsorption system is endothermic, while the low value of ΔH° reveals that this adsorption system may operate by physical adsorption.

The positive value of ΔS°,0.13 J mol K^{-1}, resulted from the randomness increase at the solid-liquid interface during RB dye molecule adsorption. The ΔS°positive value suggests a good affinity of RB towards the activated Muscovite adsorbent.

Table 6. Thermo dynamical parameters for the adsorption of RB dye.

Parameters		RB dye
ΔH°, kJ/mol		16.1
ΔS°, kJ/ mol K		0.13
ΔG°, kJ/mol	298 k	-2.64
	308 k	-3.94
	318 k	-5.24
	328k	-6.54
R^2		0.9908

CONCLUSIONS

In this study, a chemically prepared activated Muscovite adsorbent was applied for the removal of RB dye. The optimum parameters for maximum removal of RB dye on the developed adsorbent were observed at 30 ppm RB concentration, pH 3, solution temperature 25°C, contact time 60 min, and 2 gm dosage.

Isotherm models (Freundlich, Langmuir, Dubunin–Radushkevich, and Temkin isotherm models) were applied for adsorption of RB dye on the Muscovite adsorbent. The RB dye adsorption on Muscovite adsorbent fitted Langmuir isotherm model. The kinetics adsorption was checked by the pseudo-first order, pseudo-second order, intraparticle diffusion, and Elovich models. From all these four kinetic models, adsorption of RB dye on Muscovite adsorbent follows pseudo-second order kinetic model. The thermodynamics parameters of adsorption of RB dye indicated spontaneous and endothermic process.

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