

Kinetics and mechanism of removal of methylene blue by adsorption onto perlite

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Abstract

The kinetics and mechanism of methylene blue adsorption on perlite have been studied. The effects of various experimental parameters, such as initial dye concentration, temperature and pH on the adsorption rate were investigated. Adsorption measurements show that the process is very fast and physical in nature. The extent of the dye removal increased with increase in the initial concentration of the dye and the initial pH and temperature of solution. Adsorption data were modelled using the first and second-order kinetic equations, mass transfer and intra-particle diffusion models. It was shown that the second-order kinetic equation could best describe the sorption kinetics. The diffusion coefficient, D , was found to increase when the initial dye concentration, pH and temperature were raised. Thermodynamic activation parameters, such as ΔG^* , ΔS^* and ΔH^* , were calculated.

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Keywords: Perlite; Methylene blue; Thermodynamic activation parameters; Kinetics of adsorption; Dye; Intra-particle diffusion; Rate constants

1. Introduction

The thermodynamic characterization of a solid–liquid interface is very important for a wide range of problems in pure and applied surface science. This is also of great interest in the case of the textile industry because of their practical applications. In fact, dye adsorption depends to a large extent on the surface free energy interactions involved. Although such systems are usually complicated, an investigation of the adsorption kinetics and thermodynamic properties provides better information concerning with mechanism of the adsorption [1]. The rate at which dye molecules are transferred to the adsorbent may be influenced by the transport of dye through the bulk solution to the surface of the adsorbent, the possible adsorption of dye molecules onto this surface, and the diffusion of the dye from the surface to the interior of the adsorbent [2].

The adsorption characteristics of dyes on various adsorbents have previously been extensively investigated for many purposes of separation and purification. However, most of the work was on the adsorption behaviour of activated car-

bon and carbon black samples. Wu et al. [3] measured the rates of adsorption of dyes and Cu(II) from water using chitosan and showed that the adsorption of reactive dyes and Cu(II) could be best described by the intra-particle diffusion model. Salem and El-Maazawi [4] studied the kinetics and mechanism of color removal of methylene blue with hydrogen peroxide catalyzed by some supported alumina surface. Banerjee et al. [5] investigated the adsorption kinetics of *o*-xylene by fly ash and demonstrated that the adsorption reaction can be approximated to first-order reversible kinetics. Batabyal et al. [6] found that the rate of removal of 2,4-dimethyl phenol from aqueous solution with coal fly ash was the first-order kinetics and that adsorption isotherms correlated reasonably well with Langmuir and Freundlich adsorption isotherms. Kannan and Sundaren investigated the kinetics and mechanism of removal of methylene blue by adsorption on various carbons and found that the kinetics of adsorption were first-order with regard to intra-particle diffusion rate [7]. Al-qodah investigated the adsorption of dyes using shale oil ash and demonstrated that the adsorption isotherm data were fitted to Langmuir isotherm and, calculated the external mass transfer coefficient [8]. Ho and McKay were made a kinetic study of dye adsorption by biosorbent waste product pith [9]. Tsai et al. studied the adsorption of acid dye onto activated carbons prepared from

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Nomenclature

C_0	initial dye concentration in aqueous solution (mol L^{-1})
C_t	dye concentration in solution at any time t (mol L^{-1})
D	diffusion coefficient ($\text{cm}^2 \text{s}^{-1}$)
E_a	activation energy (kJ mol^{-1})
k_{dif}	intra-particle diffusion rate constant ($\text{mol s}^{-1/2} \text{g}^{-1}$)
K	adsorption constant (L mol^{-1})
k_1	adsorption rate constant for first-order kinetic equation (s^{-1})
k_2	adsorption rate constant for second-order kinetic equation ($\text{g mol}^{-1} \text{min}^{-1}$)
M	mass of adsorbent (g)
q_e	equilibrium dye concentration on adsorbent (mol g^{-1})
q_t	the amount of dye adsorbed per unit mass of the adsorbent at any time, t (mol g^{-1})
r_0	the radius of the adsorbent particle (cm)
R_g	gas constant ($\text{J K}^{-1} \text{mol}^{-1}$)
R^2	linear regression coefficient
S_S	the surface area of adsorbent ($\text{m}^2 \text{g}^{-1}$)
t	time (s)
T	temperature (K)
$t_{1/2}$	the half-adsorption time of dye (s)

Greek letter

β_L	mass transfer coefficient (m s^{-1})
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agricultural waste bagasse by ZnCl_2 activation and found that the Langmuir model appears to fit the isotherm data better than the Freundlich model [10]. The cost of these adsorbent minerals indicates that cheaper and easily obtainable unconventional adsorbents should also be studied for the removal of pollutants from water. In this study, perlite, a glassy volcanic rock, has been chosen as an adsorbent, which is essentially a metastable amorphous alumina silicate [11].

In our previous works, we investigated the electrokinetic properties [11] and surface titrations [12] of perlite suspensions, and the adsorption of methylene blue [13] onto perlite samples. The present study is aimed to study a convenient and economic method for methylene blue removal from water by adsorption on a low cost and an abundantly available adsorbent, to gain an understanding of the adsorption kinetics, to describe the rate and mechanism of adsorption, to determine the factors controlling the rate of adsorption and to calculate the activation energy of system. The effects of solution pH, concentration and temperature on methylene blue adsorption rate have been evaluated.

Table 1
Chemical composition of perlite

Constituent	Percentage present
SiO_2	71–75
Al_2O_3	12.5–18
Na_2O	2.9–4.0
K_2O	4.0–5.0
CaO	0.5–2.0
Fe_2O_3	0.1–1.5
MgO	0.03–0.5
TiO_2	0.03–0.2
MnO_2	0.0–0.1
SO_3	0.0–0.1
FeO	0.0–0.1
Ba	0.0–0.1
PbO	0.0–0.5
Cr	0.0–0.1

2. Materials and methods*2.1. Materials*

The perlite sample was obtained from Cumaovası Perlite Processing Plants of Etibank (İzmir, Turkey). The chemical composition of the perlite found in Turkey is given in Table 1 [14]. The perlite sample was treated before using in the experiments as follows [11]: the suspension containing 10 g L^{-1} perlite was mechanically stirred for 24 h, after waiting for about two minutes the supernatant suspension was filtered through a white-band filter paper ($\Phi = 12.5 \text{ cm}$). The solid sample was dried at 110°C for 24 h, then sieved by 100-mesh sieve. The particles under 100-mesh are used in further experiments.

The cation exchange capacity (CEC) of perlite was determined by the ammonium acetate method ($25.97 \text{ meq } 100 \text{ g}^{-1}$) and density by the picnometer method (2.3 g cm^{-3}). The specific surface area of perlite was measured by BET N_2 adsorption ($1.22 \text{ m}^2 \text{ g}^{-1}$). All chemicals were A.R. grade.

2.2. Methylene blue

Methylene blue was chosen in this study because of its known strong adsorption onto solids. Methylene blue has a molecular weight of 373.9 g mol^{-1} , which corresponds to methylene blue hydrochloride with three groups of water. The structure of this dye is shown in Fig. 1.

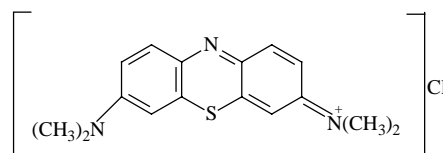


Fig. 1. The structure of methylene blue.

2.3. Method

Methylene blue was A.R. grade from Carlo Erba and was used without further purification. Methylene blue was dried at 110 °C for 2 h before use. All of the methylene blue solution was prepared with distilled water. Studies of the kinetics of methylene blue adsorption onto perlite were carried out from its solution. In systems, the dye concentration was $2.5 \times 10^{-4} \text{ mol L}^{-1}$, except those in which the effect of concentration was investigated. For the experiments of adsorption kinetics, 10-g-perlite sample was added into a litre of methylene blue solution at desired concentration, temperature and pH. The pH of the solution was adjusted with NaOH or HNO₃ solution by using a Orion 920 A pH-meter with a combined pH electrode. pH-meter was standardized with NBS buffers before every measurement. A preliminary experiment revealed that about 30 min times is required for the adsorption process to reach the equilibrium concentration. A magnetic stirrer at 30 °C and 500 rpm for 30 min continuously agitated the mixture. A constant temperature bath was used to keep the temperature constant. At the end of the adsorption period, the solution was centrifuged for 15 min at 5000 rpm. The samples at appropriate time intervals were pipetted from the reactor by the aid of the very thin point micropipette, which prevents the transition to solution of perlite samples. Preliminary experiments had shown that the effect of the separation time on the amount of adsorbed dye was negligible. The amount of adsorbed dye on perlite at any time, t , was determined from absorbency as measured with a Cary [1E] UV-Vis Spectrophotometer (Varian) at a 663 nm wavelength, at which the maximum absorbency occurred. The amounts of dye adsorbed were calculated from the concentrations in solutions before and after adsorption. Each experimental point was an average of two independent adsorption tests [15].

3. Results and discussion

3.1. Adsorption rate

Adsorption rate was investigated using the values of dye adsorbed at different initial dye concentrations, temperatures and pHs as a function of reaction time.

3.1.1. Effect of initial adsorbate concentration on adsorption process

To determine proper methylene blue adsorption and equilibrium time, initial concentrations of methylene blue solutions were changed and time intervals were assessed until no adsorption of adsorbate on perlite takes place. Fig. 2 shows the extent of dye adsorption as a function of reaction time. Results show that dye adsorption reaches equilibrium adsorption in 30 min. Based on these results, thirty minutes was taken as the equilibrium time in kinetic adsorption experiments. The curves in Fig. 2 relate amounts of methylene

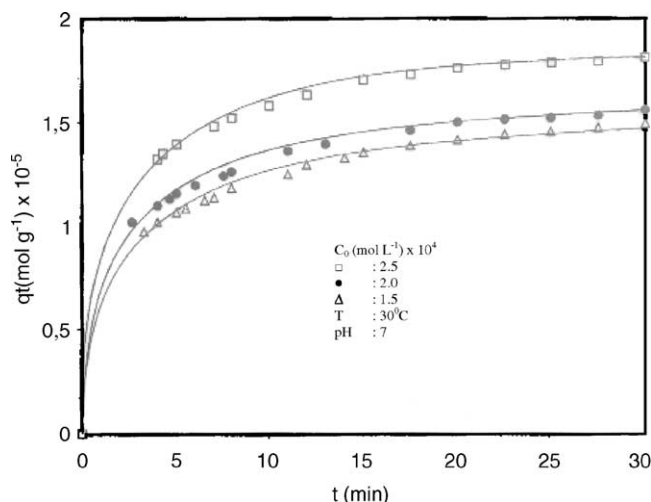


Fig. 2. The effect of concentration on the removal of methylene blue.

blue adsorbed onto perlite from its 1.5×10^{-4} , 2.0×10^{-4} and $2.5 \times 10^{-4} \text{ mol L}^{-1}$ solutions at $\text{pH} = 7$ and 30°C . Here, q_e represents the ratio of adsorbed amount of methylene blue to the gram amount of adsorbent (mol g^{-1}). The removal of methylene blue from aqueous solutions by adsorption on perlite increases with time, till the equilibrium is attained in 30 min. It is further noted that the amount of methylene blue adsorbed decreases from 1.81×10^{-5} to $1.49 \times 10^{-5} \text{ mol g}^{-1}$ by decreasing the concentration of the adsorbate solution from 2.5×10^{-4} to $1.5 \times 10^{-4} \text{ mol L}^{-1}$ at $\text{pH} = 7$ at 30°C . The time-rate adsorption curves (Fig. 2) are single smooth and continuous leading to saturation at various concentrations of methylene blue on the outer interface of perlite. This shows the possibility of monolayer coverage of methylene blue on the outer interface of perlite [16].

3.1.2. Effect of temperature on adsorption process

The temperature has two major effects on the adsorption process. Increasing the temperature is known to increase the rate of diffusion of the adsorbate molecules across the external boundary layer and in the internal pores of the adsorbent particle, owing to the decrease in the viscosity of the solution. In addition, changing to temperature will change the equilibrium capacity of the adsorbent for a particular adsorbate [8]. Fig. 3 shows the results of contact time experiments carried out at different temperatures for methylene blue adsorption on perlite. The removal of methylene blue by adsorption on perlite increases from 1.81×10^{-5} to $2.35 \times 10^{-5} \text{ mol g}^{-1}$ by increasing the temperature of the solution from 30 to 60°C , indicating the process to be endothermic. This kind of temperature dependence of the amount of the dye adsorbed may reflect the increase in the case with which the dye penetrates into the perlite because of its larger diffusion coefficient. In fact, a possible mechanism of interaction is the reaction between the hydroxyl endgroups of the perlite and the cationic group in the dye molecules

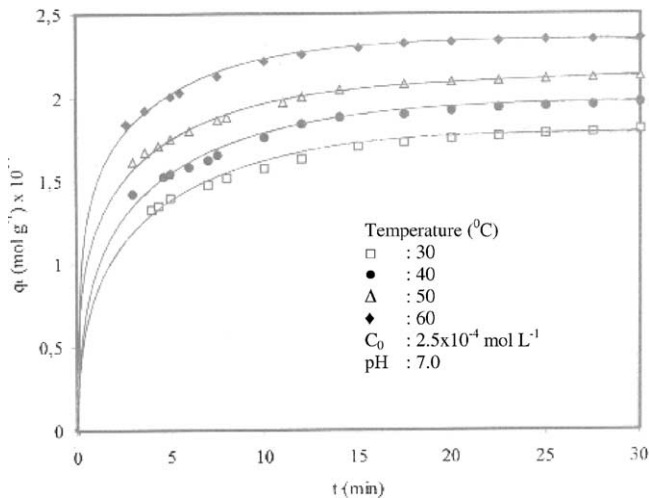


Fig. 3. The effect of temperature on the removal of methylene blue.

such a reaction could be favoured at higher temperatures [17].

3.1.3. Effect of pH on adsorption process

The pH is one of the most important factors controlling the adsorption of dye onto suspended particles. As the pH increases, it is usually expected that the adsorption also increases. Fig. 4 shows the extent of dye adsorption at different pHs as a function of reaction time. The removal of methylene blue by perlite increases from 1.57×10^{-5} to $2.00 \times 10^{-5} \text{ mol g}^{-1}$ when the pH of dye solution, $2.5 \times 10^{-4} \text{ mol L}^{-1}$, was changed 5–11 at 30°C . It is remarkably noted from zeta potential and surface charged values that the perlite surface is negatively charged in a wide pH range (3–11) [11]. With the increasing pH values, the adsorption of methylene blue on perlite tends to increase, which can be explained by the electrostatic interaction of dye cationic species with the negatively charged surface. The electrostatic attraction force of the dye compound with perlite surface is likely to be raised when the pH value increases [18].

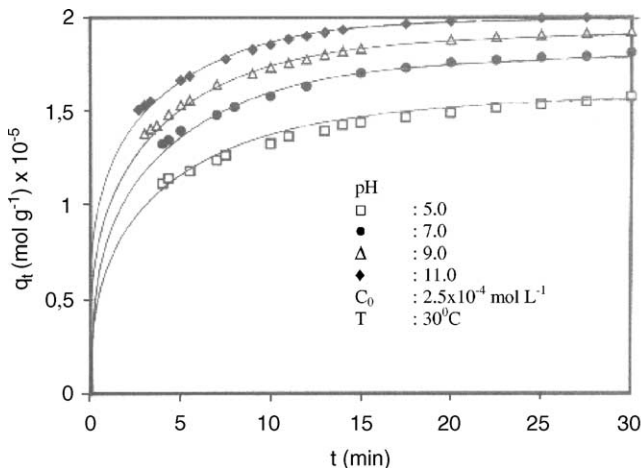


Fig. 4. The effect of pH on the removal of methylene blue.

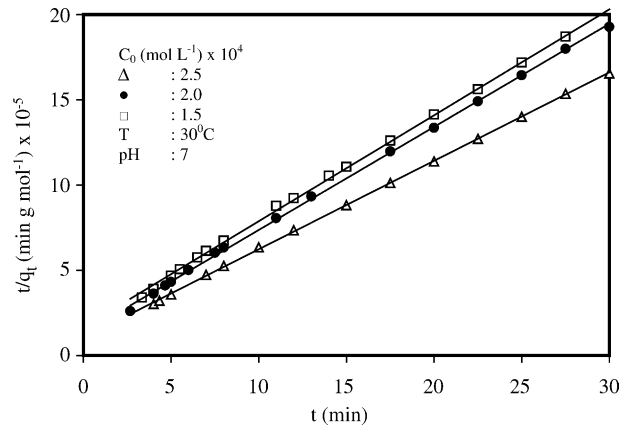


Fig. 5. Second-order kinetic equation for adsorption of methylene blue on perlite at different initial dye concentrations.

3.2. Adsorption kinetics

The rate constant of adsorption is determined from the first-order rate expression given by Lagergren and Svenska [19]:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (1)$$

where q_e and q_t are the amounts of methylene blue adsorbed (mol g^{-1}) at equilibrium and at time t (min), respectively, and k_1 the rate constant of adsorption (min^{-1}). Values of k_1 were calculated from the plots of $\ln(q_e - q_t)$ versus t (figures not shown) for different concentrations, pHs and temperatures of methylene blue. Although the correlation coefficient values are higher than 0.99, the experimental q_e values do not agree with the calculated ones, obtained from the linear plots (Table 2). This shows that the adsorption of methylene blue onto perlite is not a first-order reaction.

The second-order kinetic model is expressed as [20]:

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

where k_2 is the rate constant of second-order adsorption ($\text{g mol}^{-1} \text{ min}^{-1}$). If the second-order kinetics is applicable, then the plot of t/q_t versus t should show a linear relationship. There is no need to know any parameter beforehand and the equilibrium adsorption capacity, q_e , can be calculated from Eq. (2). Also, it is more likely to predict the behavior over the whole range of adsorption. Values of k_2 and q_e were calculated from the intercept and slope of the plots of t/q_t versus t . The linear plots of t/q_t versus t (Figs. 5–7) show a good agreement between experimental and calculated q_e values (Table 2). The correlation coefficients for the second-order kinetic model are greater than 0.999 indicating the applicability of this kinetic equation and the second-order nature of the adsorption process of methylene blue on perlite. Similar phenomena have been observed in the biosorption of remazol black B on biomass [21] and adsorption of congo red [22] and 2-chlorophenol [23] on coir pith carbon.

Table 2
Kinetics values calculated for methylene blue adsorption on perlite

Parameters	First-order kinetic model			Second-order kinetic model		Mass transfer		Intraparticle diffusion		D ($\times 10^9$ $\text{cm}^2 \text{s}^{-1}$)	$t_{1/2}$ (s)			
	Concentration ($\times 10^4 \text{ mol L}^{-1}$)	pH	q_e (exp.) ($\times 10^5 \text{ mol g}^{-1}$)	k_1 ($\times 10^3 \text{ s}^{-1}$)	q_e (calculated) ($\times 10^6 \text{ mol g}^{-1}$)	R^2	q_e ($\times 10^5 \text{ mol g}^{-1}$)	k_2 (g $\text{mol}^{-1} \text{ s}^{-1}$)	R^2			R^2	C	
30	1.5	7	1.49	2.01	8.19	0.9937	1.50	385	0.9991	0.9802	0.63	0.9979	2.42	174
30	2.0	7	1.56	2.02	7.47	0.9981	1.65	459	0.9994	0.9816	0.66	0.9965	3.02	140
30	2.5	7	1.81	2.30	8.59	0.9989	1.92	428	0.9998	0.9877	0.86	0.9965	3.27	129
40	2.5	7	1.97	2.60	9.29	0.9949	2.08	460	0.9997	0.9861	1.03	0.9995	3.82	110
50	2.5	7	2.13	2.80	8.80	0.9981	2.22	577	0.9999	0.9884	1.21	0.9968	5.19	81
60	2.5	7	2.35	3.10	8.66	0.9989	2.43	693	0.9999	0.9807	1.43	0.9913	6.87	61
30	2.5	5	1.57	1.90	7.51	0.9930	1.67	410	0.9993	0.9731	0.70	0.9944	2.72	155
30	2.5	9	1.92	2.60	9.10	0.9918	2.02	515	0.9999	0.9852	1.00	0.9965	4.17	101
30	2.5	11	2.00	3.10	9.06	0.9957	2.08	673	0.9999	0.9854	1.11	0.9954	5.68	74

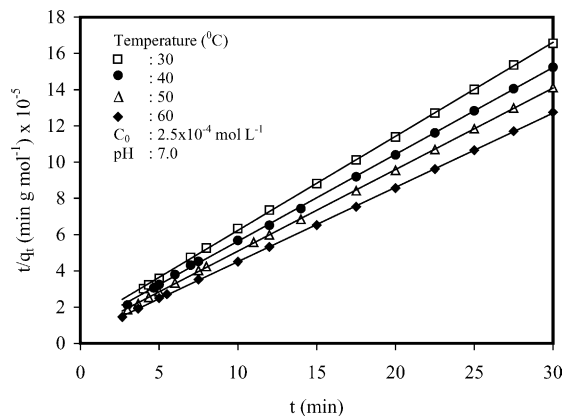


Fig. 6. Second-order kinetic equation for adsorption of methylene blue on perlite at different temperatures.

The half-adsorption time of the dye, $t_{1/2}$, i.e. the time required for the perlite to uptake half of the amount adsorbed at equilibrium, is often considered as a measure of the rate of adsorption and for the second-order process is given by the relationship [24]:

$$t_{1/2} = \frac{1}{k_2 q_e} \tag{3}$$

The determined values of $t_{1/2}$ for the tested parameters are given in Table 2.

3.3. Mechanism of adsorption

The removal of methylene blue by adsorption on perlite was found to be rapid at the initial period of contact time and then to become slow and stagnate with the increase in contact time. The removal of methylene blue by adsorption on surface of perlite was due to MB as MB^+ cationic form. The mechanism for the removal of dye by adsorption may be assumed to involve the following four steps [25]:

- Migration of dye from bulk of the solution to the surface of the adsorbent.

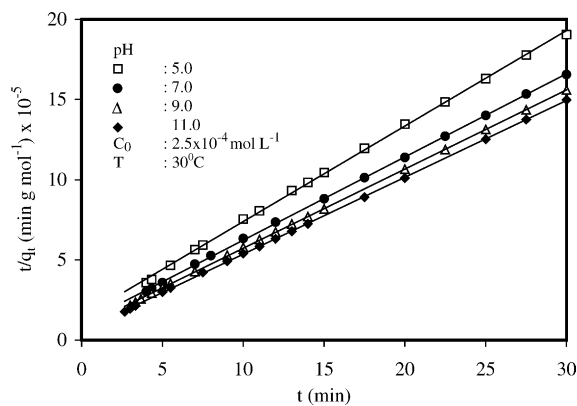


Fig. 7. Second-order kinetic equation for adsorption of methylene blue on perlite at different pHs.

- Diffusion of dye through the boundary layer to the surface of the adsorbent.
- Adsorption of dye at an active site on the surface of perlite.
- Intra-particle diffusion of dye into the interior pores of the perlite particle.

The boundary layer resistance will be affected by the rate of adsorption and increase in contact time, which will reduce the resistance and increase the mobility of dye during adsorption. The uptake of dye at the active sites of perlite can mainly be governed by either liquid phase mass transfer rate or intra-particle mass transfer rate.

3.3.1. Mass transfer coefficient

Mass transfer coefficient, β_L (m s^{-1}) of methylene blue at the perlite-solution interface, were determined by using the Eq. (4) [26]

$$\ln\left(\frac{C_t}{C_0} - \frac{1}{1+mK}\right) = \ln\left(\frac{mK}{1+mK}\right) - \left(\frac{1+mK}{mK}\right)\beta_L S_S t \quad (4)$$

where K is the Langmuir constant (L mol^{-1}), m is the mass of adsorbent (g), and S_S is the surface area of adsorbent ($\text{m}^2 \text{g}^{-1}$).

A linear graphical relation between $\ln[(C_t/C_0) - 1/(1+mK)]$ versus t was not obtained. In plotting the curves, K values for the adsorption of methylene blue onto perlite were taken from our previous work [13]. This result indicates that the model mentioned above for the system is not validity. The values of regression coefficient (r -values) calculated from equation mentioned above are given in Table 2.

3.3.2. Intra-particle diffusion model

The adsorbate species are most probably transported from the bulk of the solution in to the solid phase through intra-particle diffusion/transport process, which is often the rate limiting step in many adsorption process. The possibility of intra-particle diffusion was explored by using the intra-particle diffusion model [27].

$$q_t = k_{\text{dif}}\sqrt{t} + C \quad (5)$$

where C is the intercept and k_{dif} is the intra-particle diffusion rate constant ($\text{mol min}^{-1/2} \text{g}^{-1}$). The values of q_t were found to be linearly correlated with values of $t^{1/2}$. The k_{dif} values were calculated by using correlation analysis (Table 2). The r -values are close to unity indicating the application of this model. This functional relationship corresponds to the characteristic of intra-particle diffusion [5]. The intra-particle diffusion plots have been given in Figs. 8–10. The values of intercept (Table 2) give an idea about the boundary layer thickness, i.e., the larger intercept the greater is the boundary layer effect [7]. The applicability of intra-particle diffusion model indicates, that it is the rate-determining step.

We had found that the adsorption of methylene blue onto perlite samples were correlated reasonably well by the Langmuir isotherm in our previous study [13]. The fact that the

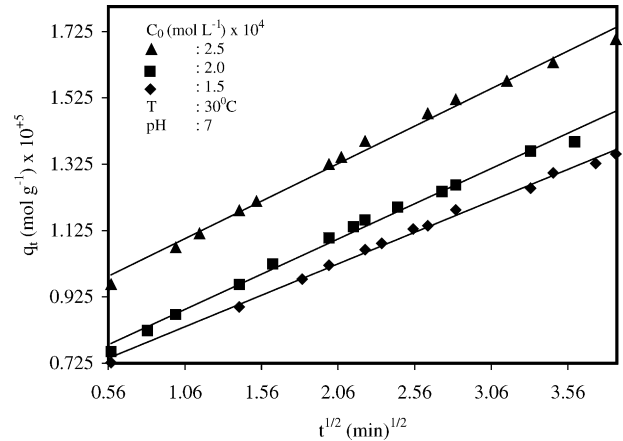


Fig. 8. Intra-particle diffusion plots for adsorption of methylene blue on perlite at different initial dye concentrations.

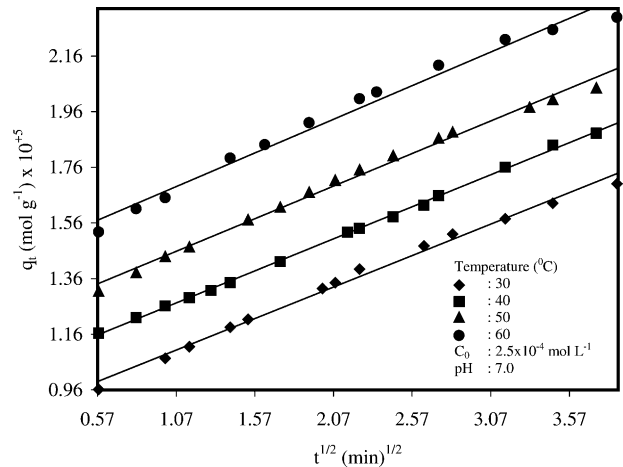


Fig. 9. Intra-particle diffusion plots for adsorption of methylene blue on perlite at different temperatures.

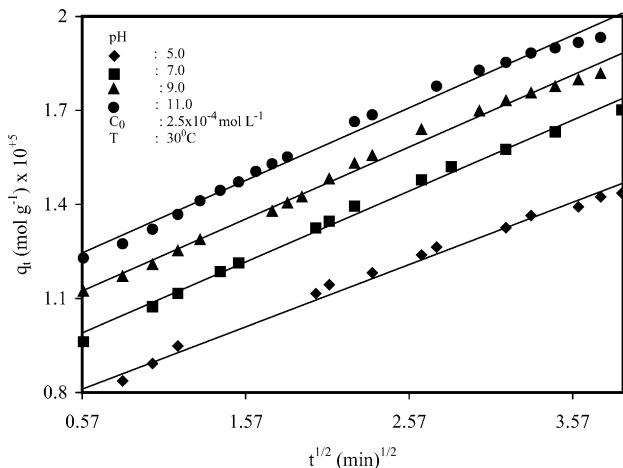


Fig. 10. Intra-particle diffusion plots for adsorption of methylene blue on perlite at different pHs.

Table 3
Reaction orders and models for adsorption of some basic dyes on various adsorbents

Adsorbent	Reaction order	Adsorbate	Reaction model	References
Activated carbons	First-order	Methylene blue	Intraparticle diffusion	Kannan and Sunduram [7]
Pith	Pseudo second-order	Basic red 22	Intraparticle diffusion	Ho and McKay [20]
Wood	–	Astrazone blue	Intraparticle diffusion	McKay and Poots [28]
Perlite	Second-order	Methylene blue	Intraparticle diffusion	In this study
Modified peat-resin particles	–	Basic magenta, basic brilliant green	Intraparticle diffusion	Sun and Yang [29]

Langmuir isotherm fits the experimental data very well may be due to homogenous distribution of active sites on the perlite surface; since the Langmuir equation assumes that the surface is homogenous. Although all of R^2 -values for both second-order kinetic model and intra-particle diffusion model are bigger than 0.99, the fact that adsorption process was very fast and adsorption values were reasonably correlated by the Langmuire isotherm have also showed that the adsorption of methylene blue occurs on the active sites onto perlite. Furthermore, q_e values calculated from the linear plots of t/q_t versus t for second-order kinetic model have showed a good agreement with experimental q_e values. As a result, it can be said that methylene blue adsorption onto perlite takes place according to second-order kinetic model.

A comparison between the adsorption orders and models of basic dyes on various adsorbents are present Table 3. This table has shown that the adsorption models of basic dyes on adsorbents such as activated carbons [7], pith [9], wood [28], modified peat-resin particle [29] and perlite are the same as and intra-particle diffusion when reaction order is the first-order for adsorption of methylene blue on activated carbons [7], second-order for adsorptions of basic red 22 on pith [9] and methylene blue on perlite.

3.4. Diffusion coefficient

The values of diffusion coefficient largely depend on the surface properties of adsorbents. The diffusion coefficients for the intra-particle transport of methylene blue within the pores of perlite particles have been calculated at different temperatures, initial dye concentrations and pH by employing the Eq. (6) [30]

$$t_{1/2} = \frac{0.030r_0^2}{D} \quad (6)$$

where D is the diffusion coefficient with the unit $\text{cm}^2 \text{s}^{-1}$; $t_{1/2}$ is the time, s, for half adsorption of methylene blue and r_0 is the radius of the adsorbent particle in cm. The value of r_0 was calculated as 3.75×10^{-3} cm for perlite sample. In these calculations, it has been assumed that the solid phase consists of spherical particles with an average radius between the radii corresponding to upper- and lower-size fractions (for $<150 \mu\text{m}$ mesh-size). For the present study, the pore diffusion coefficient values obtained from Eq. (6) are given in Table 2. The values of diffusion coefficient for adsorption of methylene blue increase from 2.42×10^{-9} to

$6.87 \times 10^{-9} \text{ cm}^2 \text{ s}^{-1}$ with change in temperature from 30 to 60°C . These results agree with those of Haimour and Sayed [31], McKay and Allen [32] and Al-qodah [8]. Compared to benzene derivatives on carbon and astrazone blue and telon blue on wood [32], the D values for methylene blue on perlite are much lower than those of benzene derivatives. The D values of phenol and benzene on carbon is 901×10^{-10} and $80 \times 10^{-10} \text{ cm}^2 \text{ s}^{-1}$, respectively. This was attributed to the larger molecular size of the present systems, the factor that slows down in diffusion rate. In addition, the present molecule has more complex structure than benzene derivatives, and therefore its strong interaction nature with perlite surface reduces its mobility. Furthermore, the diffusion coefficient values, D , for methylene blue adsorption on perlite are higher than those for astrazone blue and telon blue on wood [28]. The diffusion coefficients vary from 6.0×10^{-13} to $1.8 \times 10^{-13} \text{ cm}^2 \text{ s}^{-1}$ for astrazone blue and from 3.0×10^{-13} to $8.0 \times 10^{-13} \text{ cm}^2 \text{ s}^{-1}$ for telon blue.

3.5. Activation parameter

The activation energy was calculated from the linearized Arrhenius Eq. (7):

$$\ln k_2 = \ln k_0 - \frac{E_a}{R_g T} \quad (7)$$

where k_2 is the rate constant of sorption ($\text{g mol}^{-1} \text{ s}^{-1}$), k_0 is the temperature independent factor ($\text{g mol}^{-1} \text{ s}^{-1}$), E_a is the activation energy of sorption (kJ mol^{-1}), R_g is the gas constant ($\text{J K}^{-1} \text{ mol}^{-1}$) and T is the solution temperature (K). A plot of $\ln k_2$ versus the reciprocal of absolute temperature,

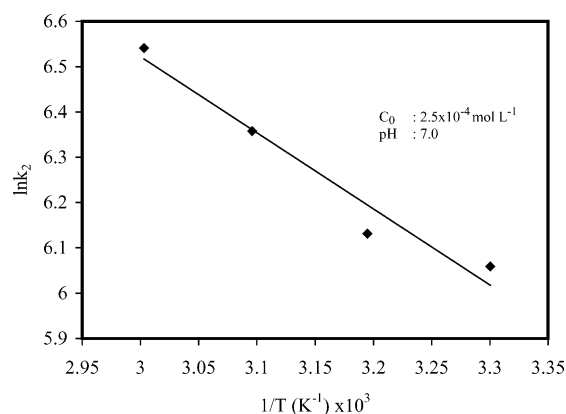


Fig. 11. Arrhenius plot for adsorption of methylene blue on perlite.

$1/T$, gives straight line as shown in Fig. 11 and the corresponding activation energy was determined from the slope of linear plot. The result obtained is $13.96 \text{ kJ mol}^{-1}$ for adsorption from its solution. As known when the rate is controlled by intra-particle diffusion mechanism, the activation energy is very low and hence it can be concluded that process is governed by interactions of physical nature [13].

3.6. Conclusions

Perlite is a capable of removing methylene blue from an aqueous solution. The initial rate of adsorption of methylene blue with perlite was high, then followed by a slower rate and gradually approached a plateau. It reaches equilibrium in 30 min. It was found that the rate constant of adsorption increased by increasing initial concentration, pH and temperatures. The results of this research demonstrate that the second-order kinetic model mechanism plays a significant role in the adsorption of methylene blue by perlite.

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