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THERMODYNAMIC FUNCTIONS AND KINETIC MODELS FOR METHYLENE BLUE ADSORPTION ON CORN STRAW PULP

دراسة ديناميكية ودوال الترموديناميكا لامتماز الميثيلين الأزرق باستخدام لب قش الذرة

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الملخص العربي

يهدف البحث الى تقييم عملية الامتماز بواسطة لب قش الذرة كمادة حيوية مازة من خلال دراسة حركية امتزازه لصبغة الميثيلين الأزرق ووصف عملية الامتماز من خلال دراسة الدوال الترموديناميكية وهي: الإنثالبي (ΔH) العشوائية (ΔS) والطاقة الحرة (ΔG). وقد تم حساب معدل الامتماز عند المتغيرات المؤثرة على عملية الامتماز وهي التركيز الابتدائي للصبغة، حجم حبيبات المادة المازة، كمية المادة المازة، رقم الأس الهيدروجيني وزمن العملية. وقد أوضحت النتائج أن عملية الامتماز للصبغة تحدث تدريجياً ووجد أن معدل الامتماز يكون سريع جداً في المرحلة الأولى من العملية (initial rapid rate) ثم بعد ذلك تتم العملية بمعدل منخفض (slower range) التي أن تصل لحالة الاتزان (equilibrium). وقد وجد أن النسبة المئوية لعملية الازالة تزداد مع نقص التركيز الابتدائي للصبغة وزيادة كمية المادة المازة المستخدمة حيث وصلت الى حوالي 91% عند درجة حرارة 25 م° وعند رقم الأس الهيدروجيني من 5-9. وقد استخدمت أربعة نماذج رياضية في معالجة النتائج ومن ثم تم تقييم هذه النماذج من حيث أهم أكثر تطابقاً مع النتائج العملية وهي: pseudo first-order, pseudo second-order, Elovich and intraparticle diffusion) وقد وجد أن النموذج الثاني the pseudo second-order أكثر تطابقاً مع النتائج العملية حيث كان لمعامل التصحيح أعلى قيمة. كما أوضحت نتائج الدوال الترموديناميكية أن عملية الامتماز عملية تلقائية كما أنها ماصة للحرارة مما يتطابق مع زيادة كفاءة عملية الامتماز بزيادة درجة الحرارة المستخدمة من 25 م° الى 60 م°.

ABSTRACT

Methylene Blue (MB) in aqueous solutions was subjected to color removal by the adsorption technique onto corn straw pulp (CSP) as a biosorbent waste agricultural material. Results obtained indicate that the removal efficiency of Methylene Blue at 25°C exceeds 91% and that the adsorption process is highly pH-dependent. The optimum pH lies between 5 and 9. The amount of Methylene Blue adsorbed from the aqueous solution increases with the increase of the initial Methylene Blue concentration and temperature. Smaller adsorbent particles help in increasing the percentage removal of Methylene Blue. The results fit the BET model for adsorption of Methylene Blue on corn straws pulp, verify the assumption that the adsorbate molecules could be adsorbed in more than one layer thick on the surface of the adsorbent. A comparison of kinetic models (pseudo first-order, the pseudo second-order, Elovich and intraparticle diffusion kinetic models) at different conditions showed that the pseudo second-order kinetic model correlate the experimental data well. Van't Hoff equation was used to evaluate the thermodynamic parameters (ΔH , ΔS and ΔG) for the interpretation of the adsorption process. The values of the thermodynamic parameters indicate that all adsorption processes are endothermic, and this is in agreement with the increasing adsorption capacity with temperature. The process of removal of MB by Corn straw pulp is a spontaneous one.

1. INTRODUCTION

Cationic dyes, such as MB, were used initially for dyeing of silk, leather, plastics, paper, and cotton mordant with tannin, as well as for the production of ink and copying paper in the office supplies industry [1]. In the textile sector, an estimated 10–20% of dyes (active substance) used is lost in residual liquors through the exhaustion and washing operations [2]. The releasing of dyes to the environment can cause acute and/or chronic effects on the exposed organisms, adsorb or reflect sunlight entering into water, and thus result in change of food chain [3].

Previous studies found that MB molecules existed as dimer or as aggregates at the surface, as well as a protonated form depending on the concentration and the surface properties [4]. Such extensive use of dyes and pigments often poses problems in the form of colored wastewater that require pre-treatment for color removal prior to disposal into receiving water bodies or publicly owned treatment works [5]. The main problem for dyestuff manufactureres and users is the removal or reducing the quantity of color in effluent and water sources [6].

At the present time there is no single process capable of adequate treatment [7]. Most of the existing processes include adsorption, usually with activated carbon (AC) [8]. The adsorption of the cationic dye, MB, has been used for a long time for the evaluation of the adsorption properties of AC, and in monitoring the production and quality of AC prepared from coal, in fluidized bed [9, 10]. Adsorption from dilute aqueous solutions onto solid surfaces is a highly attractive separation technique for many applications, such as wastewater

treatment, liquid mixture separation and purification, or polar organic solutes recovery from biotechnology processes [11, 12]. In particular, adsorption provides a technique of great interest to remove dyes from municipal and industrial wastewater [13, 14]. This can be achieved by using adsorbents with a high adsorptive capacity and selectivity [15].

The adsorption process can be either physical or chemical in nature, and frequently involves both. Physical adsorption involves the attraction by electrical charge differences between adsorbent and the adsorbate. Chemical adsorption is the product of a reaction between the adsorbent and the adsorbate [16]. In recent years, stringent government regulations have made it mandatory to stop such effluents, unless they are treated properly; hence, the removal of color from the effluent discharge has become environmentally important [17, 18].

2. MATERIALS AND METHODS

2.1. Preparation of Corn Straws Pulp

The corn straws pulp was rinsed a few times with distilled water and then air-dried. The washed corn straws pulp were lightly ground in a mortar and sieved through 0.5 mm and 0.05 mm diameter by means of a test sieve shaker.

2.2. Batch adsorption studies

Batch experiments with corn straws pulp were conducted to investigate the parametric effects of initial adsorbate particle size and concentration, adsorption time, pH, temperature on MB adsorption. All reagents used were of AR grade (Sigma-Aldrich, Germany). MB samples were prepared by dissolving a known quantity of the dye in distilled water and used as a stock solution and

diluted to the required initial concentration (range: 25 to 125 mg/l). 50 ml of MB solution of known concentration (C_0) was taken in a 100 ml conical flask with the required amount of adsorbent and was shaken for different time intervals in a shaker at different pH values and different temperatures. Then, the solution was filtered through a filter paper. UV-visible spectrophotometer (model PHTOMECH 301-D⁺) was employed to determine the remaining concentrations of MB in the filtrate.

3. ADSORPTION ISOTHERMS STUDY

Equilibrium studies that give the capacity of the adsorbent and adsorbate are described by adsorption isotherms, which is usually the ratio between the quantity adsorbed and that remained in solution at equilibrium at fixed temperature. Freundlich, Langmuir and BET isotherms are the earliest and simplest known relationships describing the adsorption equation [19-21]. Adsorption isotherms have been classified into six characteristic types. Microporous adsorbents produce adsorption isotherms of Type I (which has a convex shape) and it is also associated with monomolecular layer adsorption. Types II and III depict adsorption for multi-molecular layer formation while Types IV and V describe the adsorption process of multi-molecular layer formation and condensation in pores. Type VI represents surface phase transition of a monomolecular layer on a homogeneous surface [22].

3.1. Langmuir Isotherm

The Langmuir equation is used to estimate the maximum adsorption capacity corresponding to complete monolayer coverage on the adsorbent surface and is expressed by:

$$q_e = \frac{(q_{\max} K_L C_e)}{(1 + K_L C_e)} \quad (1)$$

The linearized form of the above equation after rearrangement is given by:

$$\frac{C_e}{q_e} = \frac{1}{q_{\max} K_L} + \frac{C_e}{q_{\max}} \quad (2)$$

The experimental data is then fitted into the above equation for linearization by plotting C_e/q_e against C_e .

3.2. Freundlich Isotherm

The Freundlich model named after Freundlich (1926) is an empirical equation used to estimate the adsorption intensity of the sorbent towards the adsorbate and is given by:

$$q_e = \frac{K_F C_e}{n} \quad (3)$$

Also, the value of n indicates the affinity of the adsorbate towards the adsorbent. The above equation is conveniently used in linear form as:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (4)$$

A plot of $\ln C_e$ against $\ln q_e$ yielding a straight line. The constants $1/n$ and $\ln K_F$ can be determined from the slope and intercept, respectively.

3.3. BET Isotherm

The BET (Brunauer, Emmeth and Teller) derived an adsorption isotherm based on the assumption that the adsorbate molecules could be adsorbed in more than one layer thick on the surface of the adsorbent. Their equation, assumed that the energy of adsorption holds the first monolayer but that the condensation energy of the adsorbate is responsible for adsorption of successive layers. The equation, known as the BET equation, is commonly written as follow:

$$\frac{x}{m} = \frac{ACX_m}{(C_s - C) \left(1 + \frac{(A-1)C_s}{C} \right)} \quad (5)$$

or

$$\frac{C}{(C_s - C) \left(\frac{x}{m} \right)} = \frac{1}{AX_m} + \frac{(A-1)}{AX_m} \left(\frac{C}{C_s} \right) \quad (6)$$

Thus, plotting $[C/(C_s - C)]/(x/m)$ against C/C_s will give rise to straight lines with slope $(A-1)/AX_m$ and intercept $1/AX_m$ for adsorption processes that conform BET equation.

4. ADSORPTION DYNAMICS STUDY

The study of adsorption dynamics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at the solid-solution interface. Kinetics of (MB) adsorption on the CSP were analysed using pseudofirst-order (Lagergren, 1898), pseudo second-order (Ho et al., 2000), Elovich (Chien and Clayton, 1980; Sparks, 1986) and intraparticle diffusion (Srivastava et al., 1989; Weber and Morris, 1963) kinetic models [23].

4.1. The pseudo first-order model

The pseudo first-order equation (Lagergren, 1898) is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1 (q_e - q_t) \quad (7)$$

At $t=0$ to $t=t$ and $q_t=0$ to $q_t=q_t$, the integrated form of Equation (7) becomes:

$$(\log q_e - \log q_t) = \log(q_e) - \frac{k_1}{2.303} t \quad (8)$$

where k_1 and q_e can be determined from the slope and intercept of the plot.

4.2. The pseudo second-order model

The pseudo second-order kinetic rate equation is expressed as (Ho et al., 2000):

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \quad (9)$$

At $t=0$ to $t=t$ and $q_t=0$ to $q_t=q_t$, the integrated form of Equation (9) becomes:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + kt \quad (10)$$

Equation (4) can be rearranged to obtain Equation (11), which has a linear form:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (11)$$

If the initial adsorption rate, h (mg/g.min) is:

$$h = k_2 q_e^2 \quad (12)$$

then Equations (11) and (12) become:

$$\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e} t \quad (13)$$

The plot of (t/q_t) and t of Equation (11) should give a linear relationship from which q_e and k_2 can be determined from the slope and intercept of the plot, respectively.

4.3. The Elovich model

The Elovich model equation is generally expressed as:

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad (14)$$

To simplify the Elovich equation, Chien and Clayton (1980) assumed $\alpha\beta t \gg 1$ and by applying the boundary conditions $t=0$ to $t=t$ and $q_t=0$ to $q_t=q_t$, Equation (14) becomes:

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln(t) \quad (15)$$

A plot of q_t vs. $\ln(t)$ should yield a linear relationship with a slope of $(1/\beta)$ and an intercept of $(1/\beta) \ln(\alpha\beta)$.

4.4. The intraparticle diffusion model

The intraparticle diffusion model is expressed as (Weber and Morris, 1963)

$$R = k_{id} (t)^a \quad (16)$$

A linearized form of the equation is obtained as:

$$\log R = \log k_{id} + a \log(t) \quad (17)$$

If (MB) adsorption fits the intraparticle model, a plot of $\log R$ vs. $\log t$ should yield a linear relationship with a slope of a and an intercept of $\log k_{id}$.

5. RESULTS AND DISCUSSION

5.1. Adsorption Isotherms

The results of this study show that CSP was effective, in adsorbing MB as its removal reached 91% at 25°C. Adsorption of MB was highly pH-dependent and the results showed that the optimum pH for the removal was found to be (5-9), at which MB exists mostly as the most easily adsorbed form aqueous solution increases as the initial MB concentration. Also on increasing temperature, smaller adsorbate particle were found to increase the percentage removal of MB. The Experimental data were applied in the three isotherms, which results indicate that the adsorption of MB on CSP fits the BET model (Fig. 1), verifying the assumption that the adsorbate molecules could be adsorbed in more than one layer thick on the surface of the adsorbent.

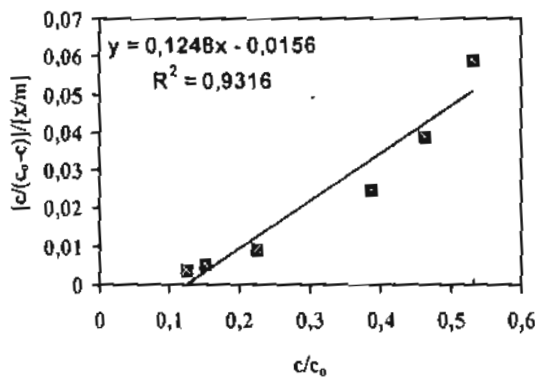


Fig. (1): Plot of BET isotherm

5.2. Adsorption Dynamics

5.2.1. Effect of adsorbate concentrations

The removal of MB by adsorption on CSP was found to increase with time and attained a maximum value at 150 min. On changing the initial concentration of MB solution from 25 to 125 mg/l, the amount adsorbed increased at 25 °C, pH 7.5 and particle size of 0.05 mm. The experimental results correlate with the theoretically predicted curves. Results

obtained show good compliance with the pseudo second-order kinetic model (Fig. 2), with values of correlation coefficient, $r^2 > 0.969$.

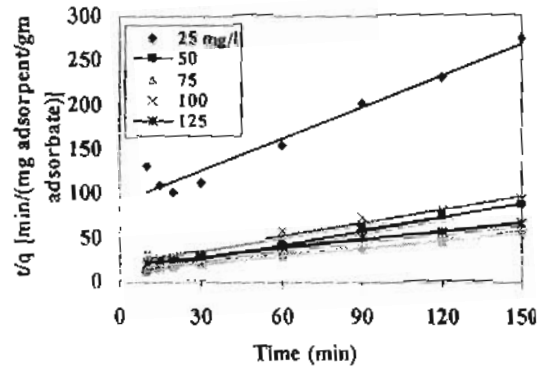


Fig. (2): Plot of pseudo second-order equation at different adsorbate concentrations

5.2.2. Effect of adsorbent particle size

The batch adsorption experiments were carried out using adsorbent with different particle sizes, (blew 0.05 to over 0.5 mm) at pH 7.5, 25°C, and initial concentration of 25 mg/l. The removal of MB increased with the decrease in particle size. The relatively higher adsorption with smaller adsorbent particle may be attributed to the fact that smaller particles yield large surface areas. The data obtained separately for each of the kinetic models from the slopes of plots, show a good compliance with the pseudo second-order equation (Fig. 3), the r^2 values for the linear plots being > 0.9644 .

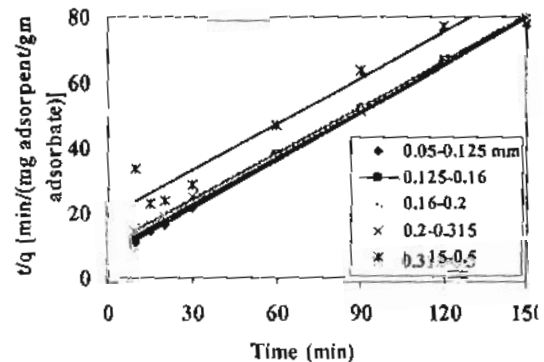


Fig. (3): Plot of pseudo second-order equation at different adsorbent particle size

5.2.3. Effect of Temperature

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 temperature will change the equilibrium capacity of the adsorbent for a particular adsorbate. The experimental data were obtained at pH 7.5, particle size blew 0.05 mm, and initial concentration of 25 mg/l. The increasing adsorption rate of MB on the surface of CSP may be explained by considering more conversion of the dimer species to monomers. The data obtained for each of the kinetic models from the slopes of plots (Fig. 4) show a good compliance with the pseudo second-order equation, with values of correlation coefficient, $r^2 > 0.9994$.

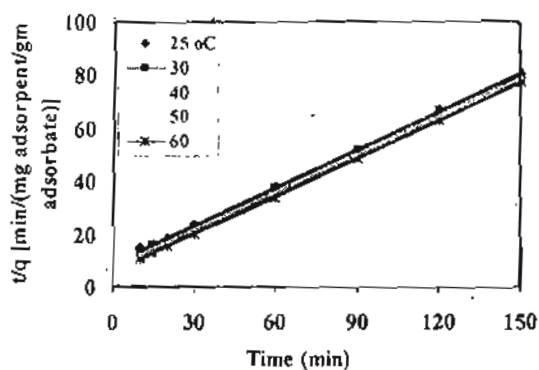


Fig. (4): Plot of pseudo second-order equation at different temperatures

5.2.4. Effect of adsorbent dose

MB uptake was studied using different doses of CSP by using 50 ml of solution at pH 7.5, 25°C, particle size blew 0.05 mm and initial concentration of 25 mg/l. The concentrations used were 0.5, 0.75, 1, 1.25 and 1.5gm adsorbent/ liter adsorbate, keeping the batch experimental volume the same in all cases. The results indicated that the percent adsorption increased with the

increase in CSP dose. The curves (Fig. 5), showed good compliance with pseudo second-order model with values of correlation coefficient, $r^2 > 0.985$.

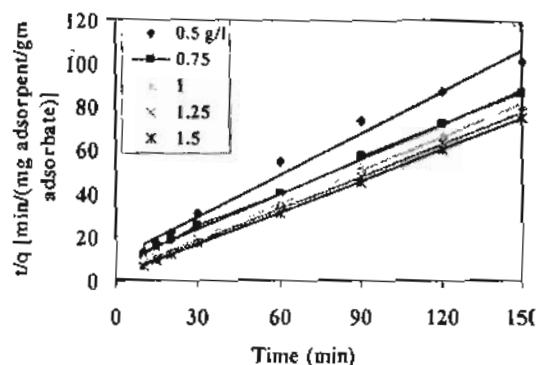


Fig. (5): Plot of pseudo second-order equation at different adsorbent dose

5.2.5. Effect of pH

The removal of MB was studied at different pHs in the range 2.2-11.1 by CSP at initial MB concentration of 25 mg/l, and a temperature of 25°C, particle size blew 0.05mm. The variation in adsorption capacity in this pH range is largely due to the influence of pH on the adsorption characteristics of the CSP which indicates that the adsorption capacity of the adsorbent is clearly pH dependent. The optimum removal (91%) was observed in the pH range 5-9. Results also showed that the adsorption reaction can be approximated with the pseudo second-order kinetic model (Fig. 6), with values of correlation coefficient, $r^2 > 0.9917$. The rate constants and values of correlation coefficient are represented in table 1.

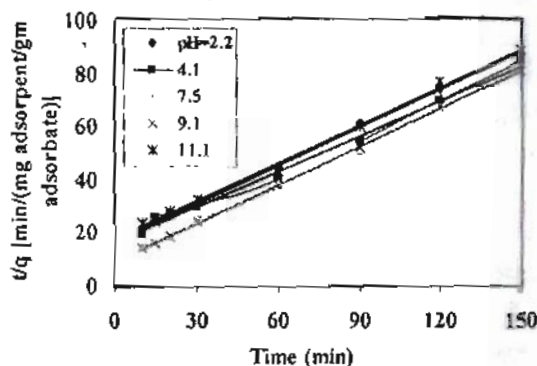


Fig. (6): Plot of pseudo second-order equation at different pH values

Table (1): The adsorption kinetic model rate constants for CSP

Parameter		First order		Second order			Elovich model			Intraparticle diffusion		
		k ₁	r ²	k ₂	h	R ²	β	α	r ²	k _{id}	a	r ²
pH	2	0.028	0.993	6.977	2.117	0.999	2.098	0.122	0.956	8.63	0.474	0.972
	5	0.039	0.992	7.368	2.264	0.992	1.916	0.123	0.923	8.25	0.495	0.960
	7.5	0.044	0.969	5.026	2.124	0.999	2.242	0.227	0.976	16.24	0.362	0.942
	9	0.039	0.996	4.689	2.085	0.999	2.345	0.257	0.811	18.02	0.339	0.952
	12	0.039	0.995	7.211	2.122	0.995	2.060	0.115	0.955	7.62	0.498	0.959
particle size (mm)	0.08	0.026	0.976	3.921	2.069	0.997	2.791		0.975	1.90	1.429	0.961
	0.1	0.034	0.993	4.420	2.081	0.999	2.506	0.528	0.970	2.01	1.330	0.971
	0.2	0.036	0.994	4.780	2.104	0.999	2.327	0.327	0.963	2.21	1.247	0.936
	0.315	0.042	0.974	5.026	2.124	0.999	2.242	0.254	0.91	2.30	1.211	0.942
	0.5	0.025	0.967	7.461	2.126	0.964	2.140	0.226	0.69	3.32	0.838	0.845
Adsorbent dose (mg/l)	0.5	0.016	0.983	3.915	1.571	0.985	3.957	0.444	0.954	21.45	0.235	0.978
	0.75	0.029	0.992	4.004	1.886	0.998	2.935	0.386	0.948	22.45	0.272	0.982
	1	0.031	0.992	2.959	1.958	0.999	3.518	1.788	0.976	35.43	0.194	0.959
	1.25	0.047	0.994	2.562	2.030	0.999	4.892	1.105	0.964	41.93	0.171	0.958
	1.5	0.041	0.996	1.877	2.072	0.999	3.692	2.837	0.834	56.40	0.116	0.957
Temperature (°C)	25	0.036	0.994	4.800	2.104	0.999	2.327	0.254	0.976	17.65	0.344	0.936
	30	0.036	0.996	4.520	2.096	0.999	2.409	0.296	0.950	19.73	0.322	0.942
	40	0.030	0.986	4.219	2.114	0.999	2.475	0.364	0.976	22.36	0.301	0.934
	50	0.030	0.989	4.064	2.128	0.999	2.525	0.417	0.902	24.44	0.284	0.950
	60	0.034	0.985	3.440	2.104	0.999	2.783	0.673	0.971	29.77	0.245	0.936
Concentration (mg/l)	25	0.023	0.994	7.169	0.841	0.995	5.672	0.027	0.976	3.78	0.668	0.936
	50	0.029	0.992	4.004	1.886	0.998	2.935	0.386	0.910	2.45	0.272	0.982
	75	0.027	0.990	8.862	3.399	0.997	1.303	0.182	0.463	6.16	0.499	0.958
	100	0.017	0.921	7.110	1.961	0.969	2.371	0.115	0.852	3.62	0.481	0.883
	125	0.019	0.997	9.621	3.010	0.992	1.508	0.135	0.849	3.53	0.523	0.986

5.3. Determination of Thermodynamic Parameters

5.3.1. Determination of ΔH°, ΔS° and ΔG°

The values of the thermodynamic parameters, enthalpy variation (ΔH) and entropy variation (ΔS), were calculated from the curve relating the distribution coefficient (K_D) as a function of temperature (Fig. 7) using the equation:

$$\ln K_D = \left(\frac{\Delta S^\circ}{R} \right) - \left(\frac{\Delta H^\circ}{RT} \right) \quad (18)$$

where K_D is the distribution coefficient (cm³.g⁻¹), defined as:

$$K_D = \frac{Q}{C_e} \quad (19)$$

with Q the amount adsorbed (mg adsorbate/g adsorbent) described by the equation:

$$Q = \frac{V(C - C_e)}{m} \quad (20)$$

where C and C_e are the initial and equilibrium concentrations of the solute, respectively (mg.cm⁻³). The calculated data for K_D and Q are shown in table 2.

The free energy change (ΔG°) parameter was calculated using equation 21:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (21)$$

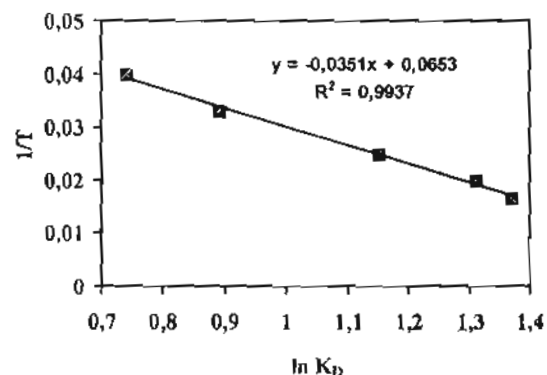


Fig. (7): Plot of 1/T versus K_D

Table 2: Q and K_D parameters at different temperatures

Temperature (°C)	Q	K_D
25	7.488	2.103
30	7.58	2.445
40	7.714	3.174
50	7.78	3.705
60	7.804	3.941

From figure 7 the values of ΔH° , ΔS° were determined from the slopes and intercepts of the curves, respectively as well as the calculated values of ΔG° and are listed in table 3. Investigation of the obtained values of the thermodynamic parameters shows that the adsorption process is endothermic. This is in accordance with increasing adsorption rate with increasing temperature.

Table 3: Thermodynamic parameters at different temperatures

ΔH kcal/mol	ΔS kcal/mol. K	ΔG (kcal/mol)				
		25 °C	30 °C	40 °C	50 °C	60 °C
0.0695	0.1293	-3.16	-3.81	-5.1	-6.39	-7.69

5.3.2. Determination of Mean Free Energy (E)

The mean free energy of adsorption (E) is the free energy change when one mole of ions is transferred to the surface of the membrane from infinity in the solution and it is calculated from:

$$E = -(2K_D R)^{-1} \quad (22)$$

The mean free energies (E) were calculated and documented in table 4.

Table 4: Free Energy (E) at different temperatures

Temperature (°C)	K_D	E, kj/mol
25	2.103	2.885807
30	2.445	3.111623
40	3.174	3.545284
50	3.705	3.830379
60	3.941	3.950489

The magnitude of E is useful for estimating the type of sorption reaction, since $E < 8$ kJ. mol⁻¹, physical forces such as

diffusional processes may affect the sorption mechanism [24]. So, the adsorption of dyes seems to be a complex phenomenon, where diffusion and chemical bonding occur at different temperature ranges, this may support that the monolayer capacity (q_{max}) increases with increasing temperature.

6. CONCLUSION

- Corn straw pulp could be used as an alternative low cost adsorbent of dyes from industrial wastewater discharged from dyeing units.
- The adsorption process fits the BET model, corroborating the assumption that the adsorbate molecules could be adsorbed in more than one layer thick on the surface of the adsorbent.
- The kinetics of MB adsorption on the CSP was found to follow a pseudo second-order rate equation.
- The mean free energies (E) revealed that, adsorption of dyes on corn straw pulp seems to be a complex phenomenon, where diffusion and chemical bonding occur at different temperature ranges.
- The values of thermodynamic parameters indicate that all adsorption processes are endothermic, and this is in agreement with the increasing adsorption capacity with temperature.
- Thermodynamic studies are performed and the values of the parameters suggest that the process of removal of MB by corn straw pulp is a spontaneous one.

7. REFERENCES

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8. NOMENCLATURE

- A Constant describing the energy of interaction between solute and adsorbent surface;
- C Initial concentration (mg/l);
- C_e Concentration equilibrium (mg/l);
- C_s Saturation concentration of solute (mg/l);
- $K_{F\&n}$ Freundlich constants;
- m Weight of adsorbent (mg);
- k_1 Rate constant of pseudo first-order adsorption (l/min);
- k_2 Rate constant of pseudo second-order adsorption (g/mg. min);
- K_D Distribution coefficient ($\text{cm}^3 \cdot \text{g}^{-1}$)
- k_{id} Intraparticle diffusion rate constant (min^{-1})
- K_L Constant related to the adsorption /desorption energy (l g^{-1});
- q_e Adsorption capacity at equilibrium, (mg of dye/g adsorbate);
- q_{\max} Maximum sorption (mg of dye/g adsorbate);
- q_t Adsorption capacity at time t , (mg of dye/g adsorbate);
- R universal gas constant (j/mole. K)

R	Percent (MB) adsorbed;	α	Initial adsorption rate (mg of dye/g adsorbate. min);
t	Contact time (min)		
V	Volume of the solution	β	Desorption constant (g/mg) during any experiment;
x	Amount of solute adsorbed (mg);		
X_m	Amount of solute adsorbed in forming a complete mono layer (mg of dye/g adsorbate);		