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Equilibrium and kinetic modeling on the removalof malachite green from aqueous solution using odina wodier bark carbon

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Abstract

Batch adsorption behavior of Malachite green(MG) from aqueous solution by using Odina Wodier bark carbon (OWC) was investigated as a function of parameters such as initial MG concentration, adsorbent dose, pH, contact time and temperature. The freundlich and langmuir adsorption models were applied to describe the equilibrium. The thermodynamic parameters such as ΔG^0, ΔH^0 and ΔS^0 were calculated to know the nature of adsorption, these values indicate that the adsorption process is favourable. The pseudo-first-order, pseudo-second-order, elovich and intraparticle diffusion models were used to describe the kinetic parameters. The high correlation coefficient (γ) was found in pseudo-second-order and intraparticle diffusion models.

Keywords: Malachite green, Odina Wodier bark Carbon (OWC), Kinetic, Thermodynamic

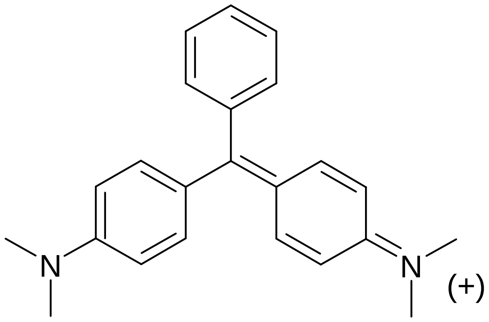
1. Introduction

Malachite green (MG) is water soluble basic triphenylmethane dye. It dissociate into anion and coloured cations. The electrostatic attraction builds up between the coloured cations and acidic groups of acrylic fibres lead to form salt and develop the colour fade upon the fabrics. The structural studies will give the idea about the adsorption mechanism involved with these dyes. The structure of malachite green is given below.

It is used as an antifungal, anti-bacterial, and anti-parasitical therapeutic agent in aquacultures and animal husbandry. It is also used as a direct dye for silk, wool, jute and leather. MG causes detrimental effects on liver, gill, kidney, intestine and gonads of aquatic organisms. Contact of malachite green with skin causes irritation with redness and pain. Intermediate products after degradation of MG are also reported to be carcinogenic [1]. Therefore, the use of malachite green in aquaculture was banned in many countries. When it was inhaled or ingested by human, it may cause irritation to the gastrointestinal tract and even cancer [2]. However, MG in fishes, animal milk and other foodstuff is still detected due to illegal use of MG [3] which is create the health hazards against human being.

The most commonly used to remove the dyes are coagulation, electrocoagulation, flotation, chemical oxidation, filtration, ion-exchange, ozonation, membrane separation, aerobic and anaerobic microbial degradation. However, all such methods suffer from one or other limitations, and none of them were successfully removing the color from wastewater.

Adsorption on activated carbons has been proven to be very effective in removing dyes from aqueous solutions. However, activated carbon is still considered to be expensive and current research is focused on the development of low-cost adsorbents for this purpose. Low-cost adsorbents include natural, agricultural, and industrial by-product wastes. Previously the grass waste [4], jackfruit peel [5] chitosan/oil palm ash [6], durian peel [7], papaya seeds [8] and rattan sawdust [9], palm ash and [10], pomelo (Citrus grandis) peel [11], sunflower seed hull [12], oil palm trunk fibre [13], and rice straw-derived charcoal [14], Firmiana simplex wood fiber[15], Seaweed Enteromorpha [16], Sulphuric acid treated marble power (SATMP)[17], Cashew nut Bark[18], acid activated Nirgudi leaf powder[19], sugarcane bagasse [20],Pandanus carbon[21], Hydrilla verticillata [22],Annona squmosa seed activated carbon [23], Surface of wool fiber[24], banana pseudo-stem fibers[25], chemically modified silica gel [26], Terminalia catappa linn carbon (TCC)[27], and borassus bark carbon [28].The objectives of our investigation were to investigate the potential of using odina wodier bark carbon (OWC) as a low-cost adsorbent to remove malachite green from aqueous solutions, to model the equilibrium and kinetics of the adsorption process.



Chemical structure of malachite green

2.Material and Methods

2.1 Adsorbate

Basic dye used in this study is Malachite green purchased from S.d fine chemicals. MG has molecular formula $C_{50}H_{52}N_4O_8$. The dye stock solution was prepared by dissolving accurate of weight dye in distilled water to the concentration of 1 g/L. The experimental solutions were obtained by diluting the dye stock solution in accurate proportions to needed initial concentrations.

2.2 Preparation of Odina wodier bark carbon (OWC) adsorbent

Odina wodier bark were washed with distilled water and cut into small pieces (1-3 cm) and dried. The air dried odina wodier bark were treated with Con. Sulphuric acid in a weight ratio of 1:1. The resulting black product was kept in a furnace maintained at 500^oC for about 12 hours followed by washing with water until free from excess acid and dried at 150 ± 5^oC, the carbon product obtained was grinded well to fine powder (30 to 50 µm size), it was used for further adsorption experiment. All chemical used for the experiments are S.d fine chemicals with high purity.

2.3 Effect of OWC adsorbent dose on the MG adsorption.

To study the effect of OWC dose on the MG adsorption, different amounts of OWC carbon (5-250 mg) were added into a 250 ml stopper glass containing a definite volume (50ml in each-flask) of fixed initial concentration (20mg/L) of dye solution without changing the solution pH at 30^oC. The flasks were placed in a thermostatic water bath shaker and agitation provided for 60 min and the dye concentrations were measured at equilibrium.

2.4 Effect of solution pH

In this study, the effect of pH on adsorption of MG on OWC was studied by mixing adsorbent dose of 25 mg/50 ml and 20 mg/L of initial dye concentration with different pH values (3.0-10.0) at 30^oC. The pH was adjusted with 0.1N NaOH and 0.1N HCl solutions and measured by using a pH meter. Agitation was made for 60 min at a constant speed.

2.5 Zero point charge

The zero point charge of the carbon (pH_{zpc}) was measured using the pH drift method [29]. The pH of the solution was adjusted by using 0.01M sodium hydroxide or 0.01M hydrochloric acid. Nitrogen gas was bubbled through the solution at 25^0C to remove the dissolved carbon dioxide. Then add 50 mg of the OWC into 50 ml of the adjusted solution. After stabilization, the final pH was recorded. The graph of final pH versus initial pH was used to determine the zero point charge of the OWC.

The pH_{zpc} of owc adsorbent is found to be 6.5.

2.6 Batch adsorption method

The batch adsorption[30] experiments were carried out by adding a fixed amount of adsorbent (25 mg) into a number of 250 ml stopper glass flasks containing a definite volume (50 ml) of different initial concentrations (10, 20, 30, 40, and 50 mg/L) of dye solutions without changing pH and at temperatures 30, 40, 50 and 60^oC. The flasks were placed in a thermostatic water bath shaker and agitation was provided to reached the equilibrium At time t=0 and equilibrium, the dye concentration were measured by UV Visible spectrophotometer at 617 nm. The amount of adsorption at equilibrium, q_e(mg/g) was calculated by the following mass balance equation.

$$q_e = \frac{(C_O - C_e)V}{W} \qquad (1)$$

Where C_o and C_e (mg/L) are the liquid phase concentrations of MG dye at initial and equilibrium respectively .V (L) is the volume of the solution. W (g) is the mass of dry adsorbent used.

The MG dye removal percentage can be calculated as follows

$$\text{Removal percentage} = \frac{C_o - C_t}{C_o} X100 \qquad (2)$$

Where C_t(mg/L) is the liquid phase concentration of dye at any time.

2.7 Batch kinetic studies:

The batch kinetic [30] experiments were basically identical to these of adsorption equilibrium method. The amount of adsorption q_t (mg/g) at time t, was calculated by

$$q_t = \frac{(C_O - C_t)V}{W} \qquad (3)$$

Where C_t(mg/L) is the liquid phase concentration of dye at any time.

3. Theory of Adsorption isotherm

To quantify the adsorption capacity of the absorbent for the removal of dyes, the most commonly used isotherm, namely freundlich and langmuir have been adopted.

3.1 Freundlich isotherm.

The linear form of freundlich isotherm [31] is represented by the equation

$$\log q_e = \log K_f + \frac{1}{n}\log C_e \qquad (4)$$

Where q_e is the amount of dyes adsorbed per unit weight of the adsorbent, (mg/L), K_f is(mg/g(L/mg)) measure of adsorption capacity and 1/n is the adsorption intensity. In general K_f value increases the adsorption capacity for a given adsorbate increases. The magnitude of the exponent 1/n gives an indication of the favorability of adsorption. The value of n>1 represents favorable adsorption condition [32, 33] (or) the value of 1/n are lying in the range of 1 to 10 confirms the favorable condition for adsorption. The linear plot of $\log q_e$ against the $\log C_e$ (figure is given) shows that the adsorption obeys the freundlich model.

3.2 Langmuir isotherm

Langmuir isotherm model [34] is based on the assumption that maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface. The linear form of the langmuir isotherm equation can be described by

$$C_e/q_e = \frac{1}{Q_m b} + \frac{C_e}{Q_m} \qquad (5)$$

Where C_e (mg/L) is the equilibrium concentration of the adsorbate, q_e (mg/g) is the amount of adsorbate adsorbed per unit mass of adsorbent, Q_m and b are langmuir constants related to adsorption capacity and rate of adsorption respectively. Q_m is the amount of adsorbate at complete monolayer coverage (mg/g) which gives the maximum adsorption capacity of the adsorbent and b (L/mg) is the Langmuir isotherm constant that relates to the energy of adsorption (or rate of adsorption). The linear plot of specific adsorption capacity $\frac{c_e}{q_e}$ against the equilibrium concentration (C_e) (figure is given) shows that the adsorption obeys the langmuir model. The langmuir constant Q_m and b were determined from the slope and intercept of the plot and are presented in table.1. In order to find out the feasibility of the isotherm, the essential characteristics of the langmuir isotherm can be expressed in terms of dimensionless constant separation factor R_L [35, 36] by the equation

$$R_L = \frac{1}{1 + bC_0} \qquad (6)$$

Where C_o(mg/L) is the initial concentration of adsorbate and b(L/mg) is langmuir isotherm constant. The parameter R_L indicate the nature of the adsorption isotherm.

$R_L > 1$	Unfavorable adsorption
$0 < R_L < 1$	Favorable adsorption
$R_L = 0$	Irreversible adsorption
$R_L = 1$	Linear adsorption

The R_L values lies between 0 to 1 indicate the process is favorable adsorption.

3.3 Thermodynamic treatment of the adsorption process.

Thermodynamic parameters associated with the adsorption, viz standard free energy change (ΔG^o), standard enthalpy change (ΔH^o), and standard entropy change (ΔS^o) were calculated as follows. The free energy of adsorption process considering the adsorption equilibrium constant K_O is given by the equation

$$\Delta G^0 = -RT \ln K_0 \qquad (7)$$

Where ΔG^O is the free energy of adsorption (J/mol), T is the temperature in kelvin and R is the universal gas constant (8.314 J $mol^{-1}K^{-1}$).The adsorption distribution coefficient K_O for the adsorption reaction was determined from the slope of the plot of $\ln(q_e/C_e)$against C_e at different temperature and extrapolating to zero C_e according to the method suggested by Khan and Singh [37]

The adsorption distribution coefficient may be expressed in terms of enthalpy change (ΔH^0) and entropy change (ΔS^0) as a function of temperature,

$$\ln K_0 = \frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R} \qquad (8)$$

Where ΔH^0 is the standard heat of adsorption (kJ/mol) and ΔS^0 is standard entropy change (kJ/mol). The value of ΔH^0 and ΔS^0 can be obtained from the slope and intercept of plot of $\ln K_0$ against 1/T. The value of thermodynamic parameter calculated from equation 7 and 8 are shown in table (3).

3.4. Adsorption kinetics

The study of adsorption kinetics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at the solid-solution interface. The kinetics of MG adsorption on the OWC were analyzed using pseudo first-order, Pseudo second-order, elovich and intraparticle diffusion kinetic models. The conformity between experimental data and the kinetic models was expressed by the correlation coefficients (γ) value, the γ values close or equal to 1. A relatively high γ value indicates that the model successfully describes the kinetics of MG dye adsorption.

3.4.1 .The pseudo first- order equation

The pseudo first-order equation [38] is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \qquad (9)$$

Where: q_e and q_t are the adsorption capacity at equilibrium and at time t, respectively.
k_1 is the rate constant of pseudo first-order adsorption (L min^{-1}). After integration and applying boundary conditions t = 0 to t = t and $q_t = 0$ to $q_t = q_t$ the integrated from of Eq. (9) becomes:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \qquad (10)$$

The values of $\log(q_e-q_t)$ were linearly correlated with t. The plot of $\log(q_e-q_t)$ vs t should give a linear relationship from which k_1 and q_e can be determined from slope and intercept of the plot, respectively. The parameter of pseudo- first-order are summarized in table .4

3.4.2. The pseudo second- order equation

The pseudo second-order adsorption kinetic rate equation is expressed as: [39, 40]

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \qquad (11)$$

Where k_2 is the rate constant of pseudo second-order adsorption (g $mg^{-1}min^{-1}$).For the boundary conditions t = 0 to t = t and $q_t = 0$ to $q_t = q_t$ the integrated form of Eq.(11) becomes:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_2 t \qquad (12)$$

This is the integrated rate law for a pseudo second-order reaction. Equation (12) can be rearranged to obtain Eq. (13), which has a linear form:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^{\,2}} + \frac{1}{q_e}t \qquad (13)$$

If the initial adsorption rate, h (mg $g^{-1}min^{-1}$) is:

$$h = k_2 q_e^2 \qquad (14)$$

then Eqs. (13) and (14) become:

$$\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e}t \qquad (15)$$

The plot of (t/q_t) and t of Eq.(15) should give a linear relationship from which q_e and k_2 can be determined from the slope and intercept of the plot, respectively. The pseudo-second-order rate constants k_2, the calculated h values, and the correlation coefficients (γ) are summarized in Table. 4.

3.4.3. The Elovich equation

The elovich model equation is generally expressed as [41, 42]:

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \qquad (16)$$

Where; α is the initial adsorption rate (mg g^{-1} min^{-1}), β is the desorption constant (g mg^{-1}) during any one experiment. To simplify the elovich equation Chien and Clayton assumed αβt>>t and by applying boundary conditions $q_t = 0$ at t = 0 and $q_{t\,=}\,q_t$ at t = t Eq. (16) becomes:

$$q_t = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln t \qquad (17)$$

If malachite green adsorption fits the elovich model, a plot of q_t vs. ln(t) should yield a linear relationship with a slope of (1/β) and an intercept of (1/β)ln(αβ). The elovich model parameters α, β, and correlation coefficient (γ) are summarized in table 4.

3.4.4. The intraparticle diffusion model

The intraparticle diffusion model used here refers to the theory proposed by Weber and Morris [43] based on the following equation for the rate constant:

$$q_t = k_{id}\, t^{1/2} + C \qquad (18)$$

Where k_{id} is the intraparticle diffusion rate constant (mg $g^{-1}min^{-1/2}$) and C is constant. If the rate limiting step is intraparticle diffusion, the graphical representation of adsorbed dye q_t (mg g^{-1}) depending on the square root of the contact time ($t^{1/2}$) should yield a straight line passing through the origin [30]. The slope of the plot of q_t vs $t^{1/2}$ will give the value of the intraparticle diffusion coefficient(k_{id}) and correlation coefficient(γ) indicate the fitness of this model. The intra- particle parameters are summarized in table 4.

4. Results and discussion

4.1. Effect of OWC dose on MG adsorption

The effect of OWC on MG adsorption was studied by varying the adsorbent concentration 5-250 mg/50 ml for MG concentration of 20 mg/L. The adsorption increases with increase in adsorbent concentration; this is due to the increase in surface area and availability of more adsorption site. The % removal of MG is greatly increases in the range of 25-150 mg/50ml after that small change occur. This is shown in Fig.1. So the optimum adsorbent carbon doses for the experiments were carried out using 25 mg/50 ml.

4.2. Effect of contact time

The effect of contact time were determined by using initial concentration of MG is 20mg/L, adsorbent dose is 25mg/50ml , and pH is 6.5 at 30^0C with different time interval such as 10,20,30,40,50,60,70 and 80 minutes are shown in figure 2. The experimental results indicate that the adsorption equilibrium was established within 40 minutes. So the further experiments were also carried out up to 40 minutes.

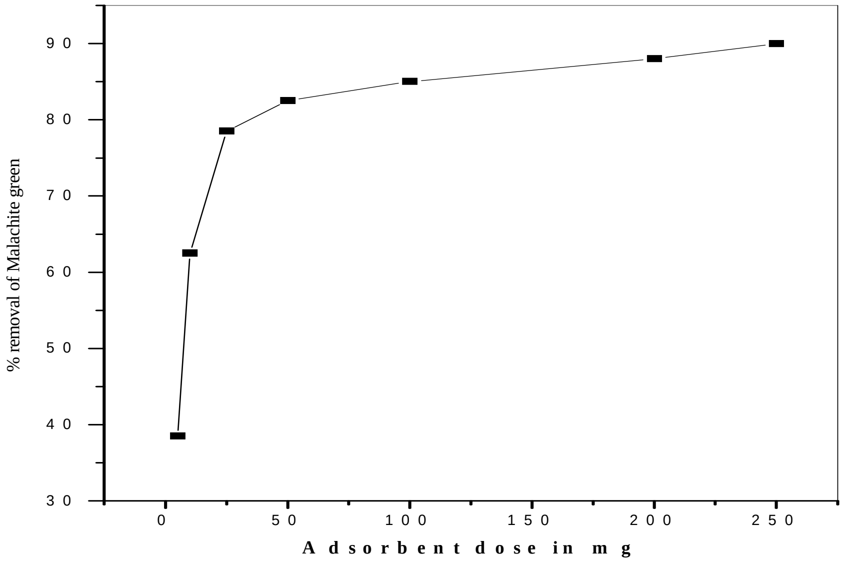


Fig.1-Effect of adsorbent dose on the removal of malachite green [MG]=20 mg/L; Contact time=60 min; Temp=30°C

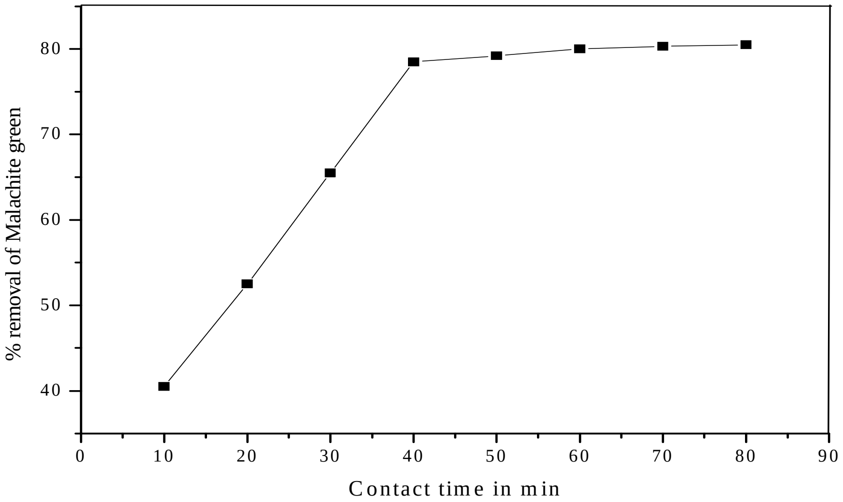


Fig.2-Effect of contact time on the removal of malachite green [MG]=20 mg/L; Adsorbent dose=25mg/50ml; Temp=30°C

4.3 Effect of solution pH

The solution pH is one of the most important factors that control the adsorption of MG on the adsorbent material. Therefore an increase in pH may cause an increase or decrease in the adsorption capacity. The adsorption capacity can be attributed to the chemical form of MG in a solution at the specific pH or due to different functional groups on the adsorbent surface. To examine the effect of pH on the % removal of MG gradually decreases as the pH increases. The pH value up to 6.5 the % removal is greater than 75% after that suddenly decreases. This may be due the dye form complex with anionic species. From the experimental results, the optimum pH range for adsorption of the MG is 3.0 to 6.5 as shown in Fig.3.

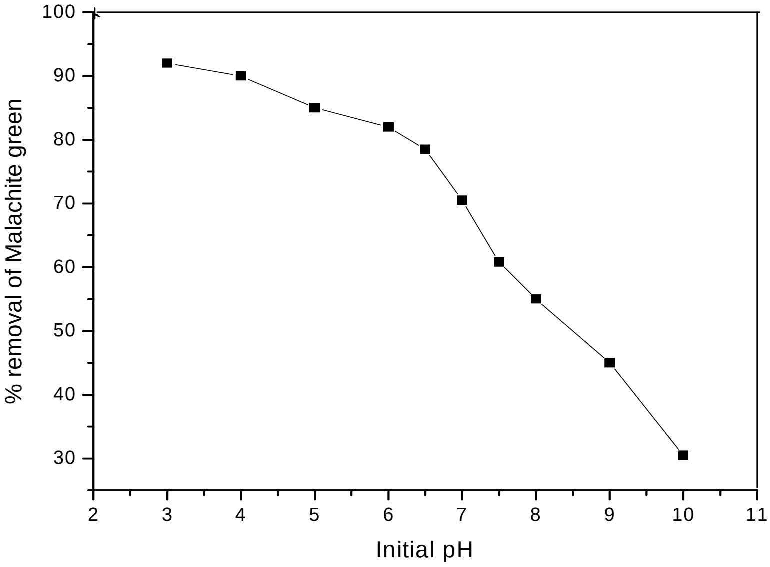


Fig.3. Effect of Initial pH on the adsorption of Malachite green [MG]=20mg/L; Contact time=60 min; Adsorbent dose =25mg/50ml

4.4. Adsorption isotherms

The significance of the adsorption isotherms is that they show how the adsorbate molecules are distributed between the adsorbent and aqueous solution at equilibrium with different temperature. Two different isotherm models were used to fit the experimental data. The freundlich and langmuir models are given in figure 4 and 5 and the parameters value are given in the table. 1.

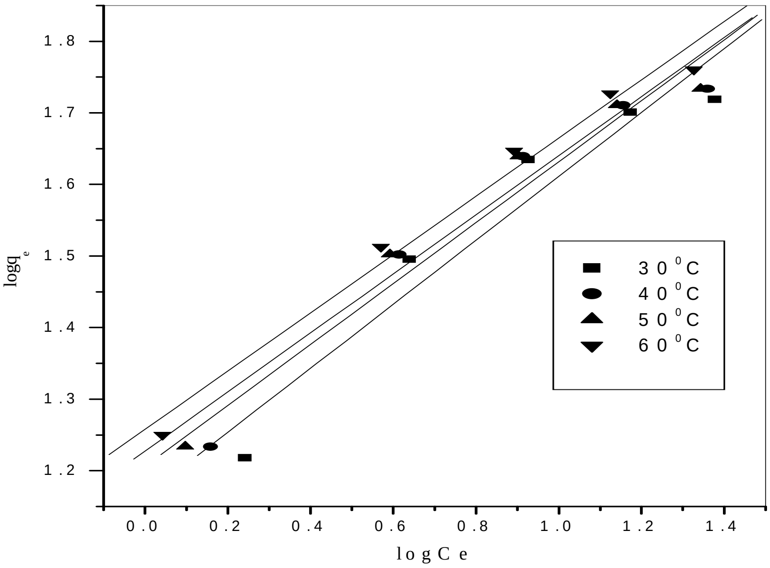


Fig.4.Freundlich isotherm for the adsorption of Malachite green

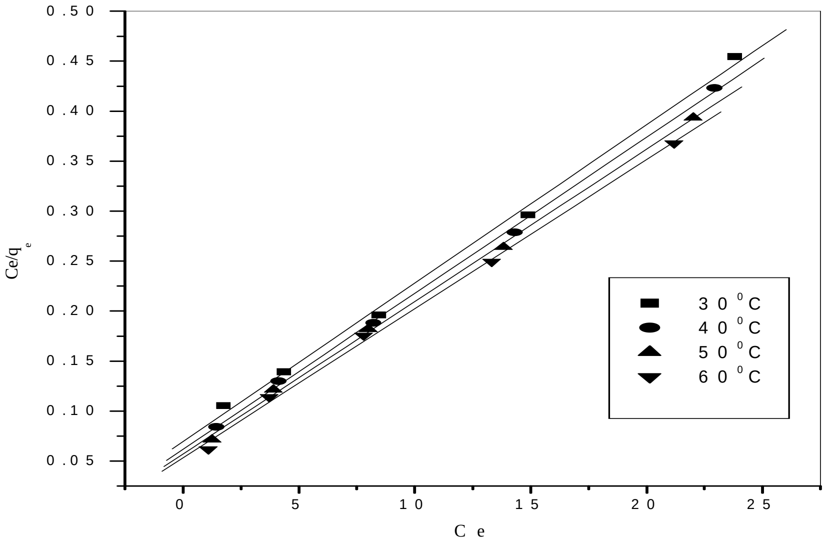


Fig.5-Linear Langmuir isotherm for the adsorption of malachite green

Table 1. Langmuir and Freundlich isotherm parameter for adsorption of MG on OWC adsorbent

Temperature(^{0}C)	Langmuir parameter		Freundlich parameter	
	Q_m	b	K_f	n
30	63.2911	.0.2273	14.6016	2.2381
40	64.1026	0.2537	16.0694	2.3485
50	65.7895	0.2666	17.1277	2.4085
60	67.1141	0.2795	18.1009	2.4564

From the table .1, it is clear that, the langmuir isotherm constant value indicate the adsorption capacity(Q_m) and adsorption intensity(b) slightly increases with increase in temperature . The freundlich isotherm parameter indicates that the adsorption capacity linearly increases with temperature and the n value indicates the adsorption is favorable process.

The langmuir isotherm can also be expressed in terms of a dimensionless constant separation factor (R_L). The R_L values calculated at different temperature are given in table. 2. The R_L values lies in between 0 to 1 indicate the adsorption process is favorable for all the initial concentration and temperature.

Table. 2. Dimensionless constant separation factor (R_L)

[MG] in mg/L	Temperature(^{o}C)			
	30	40	50	60
10	0.3055	0.2827	0.2728	0.2635
20	0.1803	0.1647	0.1579	0.1517
30	0.1279	0.1162	0.1111	0.1066
40	0.0990	0.0897	0.0857	0.0821
50	0.0808	0.0731	0.0698	0.0668

4.5. Thermodynamic parameter

The thermodynamic parameters for the adsorption process of MG with OWC are the changes in standard free energy change (ΔG^o), standard enthalpy change (ΔH^o) and standard entropy change (ΔS^o). The values of these parameters were calculated using eq. (7&8) at various initial concentrations and are shown in Table .3.

Table. 3. Thermodynamic parameter for the adsorption of MG on OWC adsorbent

C_0	ΔG^0				ΔH^0	ΔS^0
	30^0C	40^0C	50^0C	60^0C		
10	-3921.035	-4638.034	-5224.363	-5784.107	-14.8098	61.9551
20	-3221.916	-3514.042	-3799.644	-4091.014	-5.5431	28.9301
30	-2361.973	-2543.924	-2715.889	-2895.253	-3.0062	17.7216
40	-1318.762	-1521.405	-1716.342	-1923.642	-4.7686	20.0902
50	-240.8925	-434.7568	-643.5026	-849.3496	-5.9214	20.3257

The adsorption data indicates that ΔG^0 values were negative at all temperatures. The negative ΔG^0 confirm the spontaneous nature of adsorption of MG by OWC. The magnitude of ΔG^0 suggests that adsorption is physical adsorption process. The negative value of ΔH^0 were further confirms the exothermic nature of adsorption process. The positive ΔS^0 showed increased randomness at the solid –solution interface during the adsorption of MG dye on OWC adsorbent. In this condition the adsorbed water molecules, which are displaced by the adsorbate species, gain more translational entropy than is lost by adsorbate molecules, thus allowing the prevalence of randomness in the system [44]. This was also further supported by the positive values of ΔS^0, which suggest that the freedom of MG is not too restricted in the adsorbent, confirming a physical adsorption. However, the value of ΔS^0 was found to be decrease as the initial concentration increases due to the decrease the randomness of MG. The ΔG^0 value increases with increase in temperature is the increase in enhancement of the adsorption capacity of adsorbent may be due to increase or enlargement of pore size and/or activation of the adsorbent surface.

4.6. Adsorption kinetics

The kinetics of MG dye adsorption on OWC was studied with respect to different initial concentration. For evaluating the adsorption kinetics of MG, the pseudo-first-order, the pseudo-second–order, elovich model and intra -particle diffusion model were used to fit the experimental data by using linear regression analysis method. The parameters of this model are summarized in Table. 4. The high correlation coefficient (γ) values indicate the fitness of the model.

From the kinetic data, the pseudo-first- order and pseudo- second -order correlation coefficient (γ) value were almost same. The q_e value calculated from the pseudo first order model is less than that of the experimental value. But the q_e values calculated from the pseudo-second order model are nearly equal to the experimental value. So that the adsorption of MG on OWC is to follow the pseudo–second -order kinetic model. The slight increase in the h value with increase in temperature may be due to the enlargement of pore size and/or activation of the adsorbent surface.

The experimental data were used for elovich model, the initial adsorption rate(α), desorption constant(β) and the correlation coefficient(γ) are calculated. From elovich model indicate that the initial adsorption (α) increases with temperature similar to that of initial adsorption rate (h) in pseudo-second –order kinetics models. But the correlation coefficient (γ) is less than that of pseudo second order model.

The same experimental data were used for intra -particle diffusion model, the intra -particle diffusion constant (K_{id}), intercept and the correlation coefficient (γ) are calculated. From these data the intercept value indicate that the line are not passing through origin, therefore some other process that may affect the adsorption. But the correlation coefficient (γ) value is very high, so that the intra-particle diffusion takes place along with other process that may affect the adsorption process.

Table.4. The kinetic parameter for the adsorption of malachite green on OWC adsorbent

C_0	**T**	**Pseudo first Order**			**Pseudo Second order**				**Elovich Model**			**Intraparticle diffusion**		
	(°C)	**q_e**	**K_1**	**γ**	**q_e**	**K_2**	**γ**	**h**	**α**	**β**	**γ**	**K_{id}**	**γ**	**C**
10	30	1.312	0.0069	0.9985	17.8891	0.01407	0.9984	4.502	98.648	0.4609	0.9845	0.9704	0.9970	10.285
	40	1.292	0.0064	0.9997	18.4502	0.01430	0.9981	4.866	152.339	0.4729	0.9750	0.9505	0.9923	10.975
	50	1.218	0.0048	0.9981	18.5632	0.01726	0.9977	5.948	1055.79	0.5907	0.9266	0.7740	0.9592	12.377
	60	1.292	0.0064	0.9997	19.1570	0.01413	0.9983	5.186	172.119	0.4599	0.9794	0.9752	0.9947	11.500
20	30	1.328	0.0071	0.9979	34.0136	0.00702	0.9983	8.123	141.374	0.2329	0.9859	1.9189	0.9976	18.977
	40	1.323	0.0071	0.9994	34.4828	0.00696	0.9979	8.278	169.483	0.2362	0.9756	1.9027	0.9926	19.489
	50	1.326	0.0071	0.9995	34.9650	0.00682	0.9979	8.340	160.688	0.2306	0.9783	1.9461	0.9941	19.638
	60	1.376	0.0083	0.9873	35.9712	0.00585	0.9989	7.577	68.458	0.1945	0.9934	2.2770	0.9993	18.166
30	30	1.360	0.008	0.9996	47.3934	0.00453	0.9976	10.172	131.442	0.1588	0.9802	2.8236	0.9951	24.918
	40	1.364	0.008	0.9991	46.0829	0.00554	0.9991	11.764	124.603	0.1552	0.9814	2.5700	0.9982	26.248
	50	1.357	0.008	0.9997	45.8716	0.00606	0.9992	12.751	144.124	0.1578	0.9781	2.8845	0.9957	25.017
	60	1.353	0.008	0.9995	0.0554	0.9880	0.9976	10.661	149.642	0.1569	0.9791	2.8591	0.9946	25.960
40	30	1.441	0.009	16.2958	0.0564	0.9890	0.9968	9.8814	70.2125	0.1184	0.9807	3.7872	0.9954	25.652
	40	1.432	0.008	16.2256	0.0536	0.9886	0.9845	10.298	136.918	0.1368	0.8705	3.3451	0.9905	27.859
	50	1.419	0.008	0.9993	58.0046	0.00322	0.9970	10.822	90.377	0.1186	0.9794	3.7808	0.9947	27.734
	60	1.413	0.008	0.9949	58.4795	0.00327	0.9949	11.173	107.202	0.1227	0.9619	3.6745	0.9817	28.913
50	30	1.751	0.014	0.9983	58.1395	0.00211	0.9940	7.1327	25.193	0.0943	0.9792	4.7597	0.9947	18.898
	40	1.669	0.012	0.9989	59.8802	0.00216	0.9945	7.7399	29.654	0.0942	0.9795	4.7608	0.9946	20.646
	50	1.631	0.011	0.9980	61.3497	0.00224	0.9951	8.4459	35.604	0.0944	0.9802	4.7472	0.9951	22.566
	60	1.617	0.011	0.9998	64.5161	0.00206	0.9930	8.5470	31.933	0.0866	0.9757	5.1882	0.9924	22.308

Conclusion

The adsorption of MG from aqueous solution using OWC was investigated under different experimental conditions by batch process. The freundlich and langmuir adsorption capacity was found to be linearly increases. The thermodynamic parameters were found to be thermodynamically favourable physical adsorption process. The kinetic parameters with high correlation coefficient were pseudo-second-order and intra-particle diffusion models. The % removal of MG using OWC is greater than 90% by using 25mg/50 ml of adsorbent. The other adsorbent such as rice husk activated carbon is 94% [44] and carbon based adsorbent is 98% [45] also reported literature. The removal percentage greater than 90% is chosen as good adsorbent .The results of the present studies indicate that the OWC can be employed for the removal of malachite green (MG) from aqueous solution.

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