

Study of water soluble dyes adsorption from aqueous solution by *Prosopis spicigera* L. wood (PSLW) carbon

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Prosopis spicigera L. wood (PSLW), a plant material used as fuel by the rural mass in India is carbonized and used as an adsorbent for the removal of Methylene Blue and Erythrosine B dyes from aqueous solution by batch and column methods. The adsorbent is characterized by BET method (Nitrogen adsorption at 77 K) for pore and textural properties, scanning electron microscopy for surface morphology, potentiometric titration for pH_{ZPC} , FTIR for surface functional group and Boehm estimation of surface functional groups. The adsorption of Methylene Blue and Erythrosine B dyes on PSLW carbon has been carried out at different pH, adsorbate concentrations and contact time, adsorbent dosage and temperature conditions to determine the optimum condition for adsorption. Batch adsorption experiments show that maximum adsorption of Methylene Blue and Erythrosine B dyes is found at pH 2.0 and 3.0 respectively. Pseudo second order kinetics (Lagergren), surface mass transfer and pore diffusion models were used to evaluate the kinetic parameters and adsorption mechanism. To describe the equilibrium isotherm process, the data are analyzed using Langmuir model. Thermodynamic parameters indicate the adsorption interaction is found to be spontaneous and exothermic in nature. Column data fits to the Thomas Model.

Keywords: Methylene Blue, Erythrosine B, *Prosopis spicigera* L. wood (PSLW) carbon, Adsorption, Kinetics, Thomas model

The textile industry is one of the main exchequers of many countries. This economic activity generates more or less coloured waste water depending on the degree of fixation of dyes onto the substrates and this varies with the nature of substances, intensity of dyeing and the application method¹⁻³. The effluents containing dyes and pigments cause environmental problems and they are of serious concern in recent years⁴. Important methods for the removal of dyes and pigments from waste water including physical adsorption, chemical degradation, biological degradation, photo degradation, ion exchange method and reverse osmosis have been used⁵. Most of the above methods have one or another limitation and none of them are successful at economic level^{6,7}. Adsorption still exhibits advantages over other techniques because of its treatment efficiency, it does not involve any byproducts, inexpensive and fast in nature. Activated carbon is a well known material for dye adsorption but its application is restricted owing to its high production cost, if they are prepared from non-renewable sorption material such as coal⁸ etc. Therefore in recent years, this has resulted in a growing interest in the search for the production of activated carbon from cheaper renewable precursors from

agricultural by products⁸. Recently a number of low cost, easily available biological materials that have the potential of being useful as alternative adsorbents for the removal of dyes from effluents such as carrot stem and leaf powder⁹, milled sugarcane¹⁰, *achyranthes aspera* leaf powder¹¹, *strychnos potatorum* seeds¹², parsley stalks¹³, banana peels¹⁴, rice bran¹⁵, sugarcane bagasse¹⁶ etc., have been investigated. In the present work, removal of Methylene Blue (MB) and Erythrosine B (ErB) dyes from aqueous solution is attempted with carbon prepared from a dry land plant material *Prosopis spicigera* L. wood (PSLW) used as firewood, which is available all over India especially in the dry lands and deserts.

Experimental Section

Materials

PSLW plant material used in the present work was collected from the dry land area of Tiruchendur in Thoothukudi district, Tamil Nadu State, India. Activated carbon was prepared from the collected plant material as follows. The branches and roots of the tree were cut into pieces and piled up on a firing hearth. Before firing, the heaped wood pieces were

enclosed by fresh plantain pith and the whole mass was covered and plastered with layers of wet clay. This arrangement prevented the direct-entry of air into wood pieces and hence prohibited burning of wood and its becoming ash. After 48 h of continuous firing and subsequent natural cooling, the activated carbon was obtained. After removing non-carbonaceous materials like plantain pith, clay-mud etc., carbon was isolated, crushed into fine powder and sieved to 75 micron particles. The specific carbon material was stored in bottles and used as such for adsorption study after subjecting it to various physico-chemical parameters determination.

Characterisation of the adsorbent

The standard procedures^{17,18} were adopted to study the characteristics of activated carbon. BET method involving Quantasorb Jr surface analyser (USA) was applied to calculate the surface area and pore volume of PSLW carbon. Morphological study was carried out on Hitachi S 450 Japan, Scanning Electron Microscope (SEM). Potentiometric titration with acid/alkali was made to determine the zero point charge¹⁹. Fourier Transform Infra Red (FTIR) spectroscopy with Jasco FTIR 410 spectrophotometer was performed to study the nature of the surface functional groups. Boehm titration was employed to identify the surface functional groups such as carboxyl, lactone, phenol and carbonyl groups, basic and acidic sites²⁰.

Batch adsorption studies

The stock solutions were prepared by dissolving one gram of each dye (MB and ErB) separately in distilled water (1000 mg/L) and later diluted to required concentrations. A portable digital pH meter with glass electrode model LT-120 ELICO was utilized for the measurement of pH values of the aqueous phase. The initial pH value was adjusted using 0.1 mol L⁻¹ NaOH and 0.1 mol L⁻¹ HCl solutions. Batch adsorption equilibrium experiments were performed using 50 mL of dyes (MB and ErB) solution. After adsorption, the adsorbent was separated by filtration and the filtrate dye solutions were analysed by measuring absorbance at λ_{\max} 663 nm and 525 nm respectively for MB and ErB with UV-Visible spectrophotometer. The batch mode of study was performed to examine the effect of experimental parameters such as pH (1-10), initial concentration (25, 30 and 35 mg/L), contact time (5-120 min) and temperature (30-45°C). The amount

of dye adsorbed per unit mass of the adsorbent (q_e) was calculated using equation (1):

$$q_e = [(C_i - C_e) V] / W \quad \dots (1)$$

where q_e stands for the amount adsorbed at equilibrium (mg/g), C_i and C_e are the initial and equilibrium concentration of dyes (MB and ErB) (mg/L) respectively, V is the volume of dyes (MB & ErB) solution (mL) and W is the weight of the adsorbent (g). The per cent adsorption of dyes (X) was calculated using equation (2):

$$(X) = [(C_i - C_e) / C_i] \times 100 \quad \dots (2)$$

Column study

In column study, 5 g of PSLW carbon was packed in a glass column (1.5 cm diameter and 65 cm height) for a bed height of 7.5 cm. Synthetic dye (MB and ErB) solutions of various concentrations were drawn into the column at a rate of 2 mL/min from a separatory funnel fixed at a height of 1 meter. Effluents were collected at regular intervals of time and analyzed. The column flow was terminated when the ratio of the effluent to influent dyes (MB & ErB) concentration reached a value of 0.8.

Results and Discussion

Characterisation of adsorbent

The FT-IR spectra of free and dyes (MB & ErB)-loaded PSLW carbon is shown in Fig. 1. In free PSLW carbon, the peak appearing at 3444 cm⁻¹

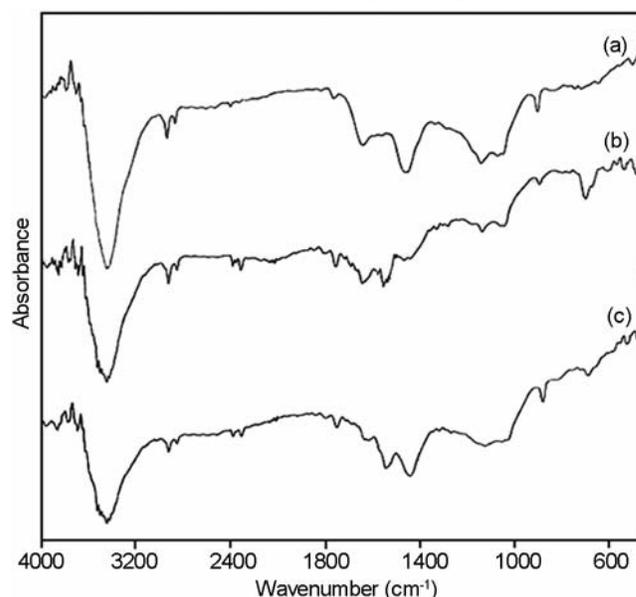


Fig. 1 — FTIR spectra of (a) free PSLW carbon (b) MB dye-loaded PSLW carbon (c) ErB -loaded PSLW carbon.

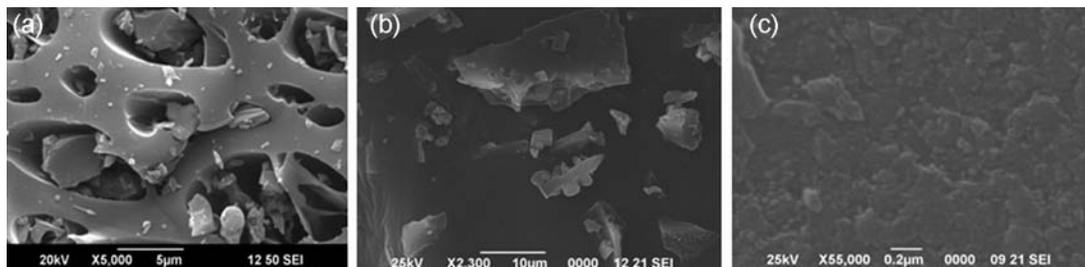


Fig. 2 — SEM images of (a) free PSLW carbon (b) MB dye-loaded PSLW carbon (c) ErB dye-loaded PSLW carbon.

attributable to -OH stretch from carboxylic groups (-COOH and -OH), while the weak band at 1623 cm^{-1} can be related to -C=O stretch from carboxylic group and the peaks at 1438 and 1024 cm^{-1} may be due to -OH in-plane bending of hydroxyl groups^{8,21} of carboxylic acid and -C=O of lactone respectively. The SEM image of free PSLW carbon powder (Fig. 2a) reveals that the carbon powder has irregularly shaped and sized particles with well developed porous structure and smooth surface. Surface area and pore volume values determined from BET method are $120.91\text{ m}^2/\text{g}$ and 0.9727 cm^3 respectively. The pH_{zpc} value is found to be 6.98 for PSLW carbon. Boehm titration (acid/base neutralization experiments) gives the quantitative estimation of surface functional groups such as carboxyl, lactones, phenols and base etc., and their concentrations are 3.44, 0.145, 0.915 and 14.5 meq/g respectively. The concentration of basic groups is higher than those of other three groups and it indicates the more prevalence of basic groups on the surface of PSLW carbon.

Effect of pH

The pH of the aqueous solution is an important controlling parameter in the adsorption process and the role of hydrogen ion concentration is examined covering a range of pH 1.0-10.0. The effect of pH on the sorption of dyes MB and ErB is shown in Fig. 3. The percentage removal of MB and ErB increases with increase in pH and maximum adsorption is noted at pH 2.0 and 3.0 respectively.

The pH_{zpc} of PSLW carbon is 6.98. Below $\text{pH} = 6.98$ the surface of the PSLW carbon is positively charged and for the cationic MB the adsorption could not be due to electrostatic attraction. But the Boehm estimation of surface functional group shows, the PSLW carbon contains maximum basic surface functional groups equal to 14.5 meq/g.

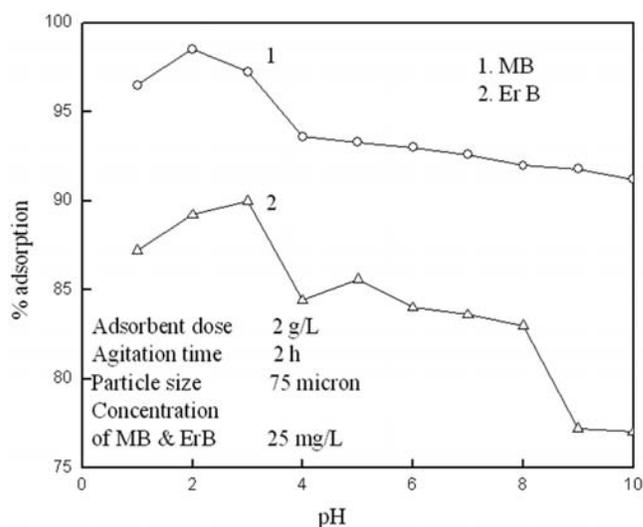


Fig. 3 — Effect of pH on adsorption of dyes (MB and ErB) on PSLW carbon.

Therefore it was initially thought that for MB the maximum adsorption at acidic pHs was due to the complex formation between the basic functional groups on the surface of PSLW carbon and cationic MB dye molecules. But electrostatic interaction is minimum, contradictory to the expectation that at pH lower than pH_{zpc} the MB dye adsorption is found to be maximum at $\text{pH} = 2.0$. The quite unexpected conclusion is emerged from the observation of desorption and IR study. The maximum dyes desorption with ethanol and chloroform (64.1 and 58% respectively) and the minimum dye desorption with sodium hydroxide (14.29%) have been observed. The lowest desorption efficiency of sodium hydroxide clearly suggests the less importance of electrostatic interaction in dye adsorption. Therefore other types of interaction particularly hydrogen bonding of $\text{-N(CH}_3)_2$ and -S^+ group of MB dye with -OH, -COOH and lactone groups of PSLW carbon; hydrophobic interaction between phenyl rings of

MB dye and PSLW carbon phase etc., also play major role in dye adsorption. This is evident from the IR spectrum of MB-loaded PSLW carbon (Fig. 1b). In IR spectrum of MB-loaded PSLW carbon the peak corresponding to hydroxyl group remains unaffected and the peak intensity at 1637 cm^{-1} is decreased. A strong evidence in favour of hydrogen bonding from dye to carbon occurs in the observation that the peaks at about 1438 and 1024 cm^{-1} due to $-\text{OH}$ in-plane bending of hydroxyl group of carboxylic acid and $-\text{C}=\text{O}$ of lactone respectively in free PSLW carbon (Fig. 1b) get shifted to higher wave number side (~ 1456 and 1039 cm^{-1}). All these IR changes on dye adsorption show the involvement of surface functional groups, (electrophilic, hydrogen bonding, hydrophobic etc.) interaction with MB dye. Further SEM analysis after adsorption (Fig. 2b), shows the presence of aggregated larger size particles with irregular shape on the surface of MB-loaded PSLW carbon indicates the adsorption of dye molecules on the surface of PSLW carbon. Hence, an optimum $p\text{H}$ of 2.0 was maintained for MB adsorption studies.

In the case of ErB dye which is anionic, at acidic $p\text{H}$ s it can be adsorbed on the surface of positively charged PSLW carbon through electrostatic interaction²¹ and this conclusion is emerged from the observation of desorption and IR study. With ethanol and chloroform, minimum dye desorption (26.8 and 7.8% respectively) and with sodium hydroxide maximum dye desorption (38.56%) have been observed. The desorption study with sodium hydroxide clearly suggests the presence of electrostatic interaction; desorption study with ethanol and chloroform suggests the presence of hydrogen bonding, hydrophobic interaction of PSLW carbon with ErB dye in dye adsorption. This is evident from the IR spectrum of ErB -loaded PSLW carbon (Fig. 1c). In IR spectrum of ErB -loaded PSLW carbon the $-\text{C}=\text{O}$ stretching frequency of lactone at 1623 cm^{-1} which is shifted to higher wave number side (1631 cm^{-1}) indicate the presence of electrostatic interaction. Further SEM analysis after adsorption (Fig. 2c), shows the presence of spherical particles on the surface of ErB-loaded PSLW carbon and this indicates the adsorption of dye molecules on the surface of PSLW carbon. Hence as an optimum, $p\text{H} = 3.0$ was chosen for further studies of ErB dye adsorption.

Effect of contact time, initial dyes concentration and adsorbent dosage

Contact time is an essential role in determining the rate and equilibrium time of adsorption process. The characteristics of PSLW carbon and its available adsorption sites affect the course of time to reach the equilibrium. For initial concentrations of dyes (MB and ErB) of 25, 30 and 35 mg/L, the adsorption capacity of dyes (MB and ErB) on PSLW was evaluated. Removal of dyes (MB and ErB) increases with increasing contact time. The adsorbent PSLW carbon shows a rapid uptake of dyes (MB and ErB) initially and a gradual/slowed uptake at later stage; the removal rate gradually slows down, and the equilibrium reaches at 60 min. After reaching the state of equilibrium, there was no significant increase in adsorption. The maximum adsorption capacity of dyes (MB and ErB) at three different initial concentrations of 25, 30 and 35 mg/L are found to be 24.58, 28.94 and 31.36 mg/g for MB; 22.76, 27.50 and 31.90 mg/g for ErB respectively.

Effect of adsorbent dosage study shows that the removal of dyes (MB and ErB) increases with the increase in adsorbent dosage and saturation attains at 500 mg/50 mL dosage. The increase in dye removal was due to the increase of the available adsorption surface sites.

Effect of temperature

To study the effect of temperature on adsorption, temperature was varied from 30 to 45°C . The adsorption capacity of PSLW carbon for MB and ErB dyes decreases with the increase in temperature. This clearly demonstrates that the adsorption of dyes (MB and ErB) onto PSLW carbon is an exothermic process.

Adsorption of MB and ErB in the presence of other ions

In order to apply this study to industrial applications, batch study was carried out in the presence of other ions such as KNO_3 , KCl and K_2SO_4 of concentration 0.1 M each. For an initial concentration of 25 mg/L of MB and ErB, the adsorption of dyes increases with time and equilibrium was reached at 60 min similar to that the adsorption of dyes in the absence of the above ions. The adsorption capacity was found to be 18.4 and 12.15 mg/g which is less than that of adsorption of dyes in the absence of the above ions.

Thermodynamic behavior

The thermodynamic constants, standard free energy (ΔG°), standard enthalpy (ΔH°) and standard entropy (ΔS°) determining the nature of thermodynamic feasibility of the adsorption process are determined using equations (3), (4) and (5):

$$\Delta G^\circ = -RT \ln K \quad \dots (3)$$

$$\log K_o = \Delta S^\circ/2.303 RT - \Delta H^\circ/2.303 RT \quad \dots (4)$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad \dots (5)$$

where R, T and K represent the universal gas constant (8.314 J/molK), temperature in Kelvin and the equilibrium constant, respectively. The values of thermodynamic parameters (Table 1) provide information for understanding the nature of adsorption process. The negative values of ΔG° indicate the spontaneous nature of adsorption process. The low value of ΔH° indicates that the nature of adsorption process is exothermic. This is also supported by the decrease in the value of uptake capacity of the adsorbent with the increase in temperature. The positive value of ΔS° shows the decreased randomness at the solid/solution interface during the adsorption process. Thus, thermodynamic parameters indicate that the adsorption process is spontaneous, and exothermic in nature.

Isotherm analysis

Isotherm analysis gives a significant physico-chemical fact for assessing the function of the adsorption process as a complete unit operation. The adsorption data are analyzed with two well-known adsorption isotherm models namely Langmuir²² and Freundlich²³ models, which are expressed by equations (6) and (7):

$$C_e/q = 1/Q_o b + C_e/Q_o \quad \dots (6)$$

$$\log q = \log K_f + 1/n \log C_e \quad \dots (7)$$

where q stands for amount of dyes (MB and ErB) adsorbed at equilibrium (mg/g), C_e is the equilibrium

concentration of the adsorbate (mg/L), Q_o is the Langmuir constant representing the maximum monolayer adsorption capacity and b is the Langmuir constant related to energy of adsorption. K_f and $1/n$ are Freundlich constants related to adsorption capacity and adsorption intensity, respectively. The experimental data did not fit well with the Freundlich model but with Langmuir model. This is evident from the linear plots of C_e/q against C_e for the adsorption of dyes (MB and ErB) on PSLW carbon (Figures not shown). Q_o and b can be determined from the slope and the intercept of the linear plots and are given in Table 2. All these facts prove that dyes (MB and ErB) are adsorbed as monolayer coverage on the surface of the adsorbent and the values shows that the adsorbent is found to be fit for dyes removal. Further the dimensionless separation factor (R_L) is calculated²⁴ using equation (8):

$$R_L = 1/1+bC_o \quad \dots (8)$$

It is observed that the fractional value of R_L (Table 1), establishes the truth that the adsorption isotherm is favorable under the studied conditions.

Adsorption kinetics

Adsorption kinetics provides the details on the adsorption mechanism of adsorbate onto an adsorbent. The kinetics of dyes (MB and ErB) adsorption on PSLW carbon was examined with pseudo-first order²⁵ and pseudo-second-order^{26,27} kinetic models which are expressed in equations (9) and (10) respectively:

$$\log (q_e - q) = \log q_e - (K_1 t / 2.303) \quad \dots (9)$$

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

where q_e and q_t are the amount of dyes adsorbed (mg/g) at equilibrium and at time 't' (min), respectively. K_1 (L/min) and K_2 (g/mg/min) are the adsorption rate constants. In addition, the initial adsorption rate h (mg/g/min) equal to $K_1 q_e$ and $K_2 q_e^2$ was also calculated. For the studied initial concentrations and temperatures, the rate constants

Table 1 — Thermodynamic parameters for the adsorption of MB & ErB dyes on PSLW carbon

Temperature (°C)	K_o		$-\Delta G^\circ$ (kJ/mol)		ΔH° (kJ/mol)		ΔS° (J/molK)	
	MB	ErB	MB	ErB	MB	ErB	MB	ErB
30	2.87	2.80	3.127	3.042				
35	2.82	2.82	3.013	3.002	2.60	1.33	0.81	4.84
40	2.85	2.85	2.989	2.988				
45	2.88	2.88	2.969	2.967				

Table 2 — Langmuir isotherm constants and equilibrium parameters

Temp (°C)	Q_o (mg/g)		b (L/mg)		R_L	
	MB	ErB	MB	ErB	MB	ErB
30	25.09	22.88	5.4728	2.368	0.0061	0.0143
35	20.28	20.88	1.5079	1.319	0.0226	0.0259
40	19.65	19.69	0.9901	0.9938	0.0326	0.0324
45	17.54	18.69	0.6397	0.8222	0.0495	0.0389

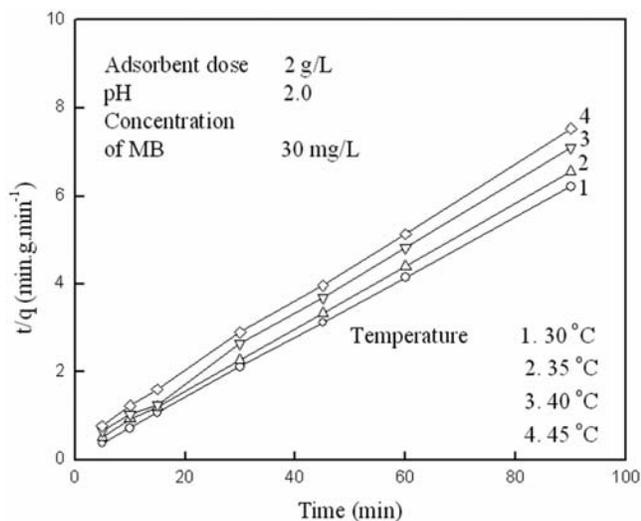


Fig. 4a — Pseudo-second order plots for MB dye at different temperatures.

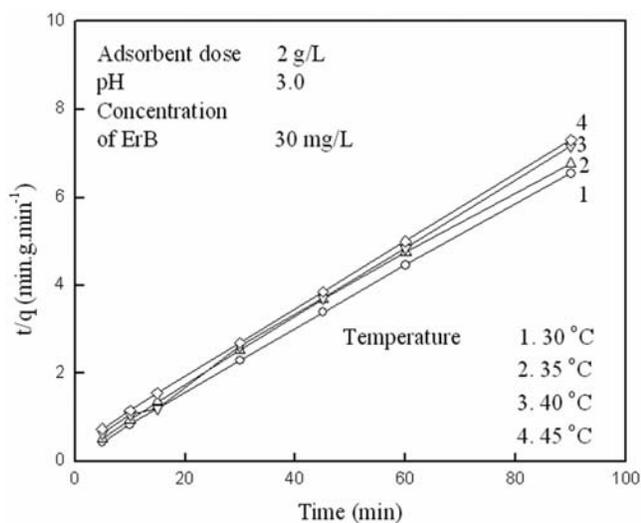


Fig. 4b — Pseudo-second order plots for ErB dye at different temperatures.

(K_1 & K_2) and theoretical equilibrium adsorption capacities, $q_e(\text{cal})$, were calculated from the slope and intercept of the linear plots of the pseudo-first order and pseudo-second order kinetic model (Figs 4a and 4b), and the co-efficient of linear correlation (R^2) are given in Table 3.

An analysis of values in Table 3, particularly the examination of agreement between $q_e(\text{exp})$ and $q_e(\text{cal})$, and the closeness of R^2 values towards unity at different initial concentrations and temperatures for both pseudo first-order and pseudo second-order models clearly reveals that pseudo second-order model fits better to the data. Therefore it is inferable

that the adsorption of dyes (MB and ErB) on PSLW carbon can be well described by Lagergren second-order kinetics. Intuitively it implies that both the dye molecules and the functional groups on PSLW carbon are crucial in accomplishing the adsorption process.

Pore diffusion

The plot of amount of adsorption versus $t_{1/2}$ is parabolic yet linear for some contact times at the initial stage and moreover they do not pass through origin (Figures not shown). The intra particle diffusion constant, K_i which is the slope of the linear portion of the plots, is determined and reported in Table 3. This pattern obviously indicating that the dye molecules slowly enter into the interior of the PSLW carbon particles through the pores, step on the surface and get entrapped in the interior.

Mass transfer study

The external mass transfer was studied using the mathematical mass transfer model proposed by McKay *et al*²⁸, which is expressed in equation (11):

$$\ln \left(\frac{C_t}{C_o} - \frac{1}{1+mk} \right) = \left[\frac{(1+mk/\beta_L S_s)}{mk} \right] t + \frac{(mk/1+mk)}{1} \dots(11)$$

where, C_o is the initial adsorbate concentration (mg/L); and C_t is the adsorbate concentration (mg/L) after time t ; m is the mass of adsorbent (g/L) per unit volume of particle free adsorbate solution; k is the Langmuir constant (L/g) obtained by multiplying adsorption capacity Q_o and adsorption energy, b ; β_L is the mass transfer coefficient (cm/S); and S_s is the outer surface area (cm^2) of the adsorbent per unit volume of particle free slurry. The values of ' m ' and S_s were calculated using the relations (12) and (13):

$$m = W/v \dots (12)$$

$$S_s = 6m / (1-\epsilon_p) d_p \rho_p \dots (13)$$

where, W is the weight of adsorbent (g); ' v ' is the volume (L) of particle free adsorbate solution; d_p is the particle diameter (cm); ρ_p is the density of adsorbent (g/cm^3) and ϵ_p is the porosity of adsorbent particle. The $\ln [(C_t/C_o - 1/1+mk)]$ versus time plots are made. It exhibits a linear behavior (Figures not shown) indicating the rapid transport of dyes from bulk to solid phase. The mass transfer coefficients are given in Table 4. The mass transfer coefficients decrease with increase in temperature.

Table 3 — Comparison of pseudo-first order and pseudo-second order kinetic parameters

C _o (mg/L)	Temp °C	q _{e,exp} (mg/g)	Pseudo first order		Pseudo second order		Intra particle diffusion K _i (mg/g/min ^{1/2})
			K ₁ × 10 ⁻² (min) ⁻¹	q _{e,cal} (mg/g)	K ₂ × 10 ⁻² (g/mg/min)	q _{e,cal} (mg/g)	
MB							
25	-	12.29	4.2	1.90	37.49	12.31	-
35	-	15.68	3.1	3.42	16.38	13.82	-
30	30	14.47	5.3	2.96	10.28	14.58	0.1738
	35	13.95	7.4	3.58	7.86	14.37	0.1426
	40	13.05	6.2	2.65	6.38	13.99	0.3018
	45	12.45	4.8	3.07	4.93	12.66	0.4039
ErB							
25	-	11.38	2.1	1.92	12.0	12.90	-
35	-	15.85	2.5	2.46	7.49	13.54	-
30	30	13.75	2.8	2.47	5.45	13.48	0.1744
	35	13.50	2.3	5.62	4.70	13.33	0.2712
	40	12.92	3.0	5.37	7.07	13.07	0.1594
	45	12.85	3.8	4.04	7.02	12.97	0.2076

Table 4 — Mass transfer coefficients at different temperatures

Temperature (°C)	Mass transfer coefficient (cm/S) × 10 ⁻³	
	MB	ErB
	30	0.0222
35	0.0137	0.0065
40	0.0081	0.0059
45	0.0054	0.0054

Table 5 — Column study at different initial concentrations

Initial concentration, (mg/L)	MB		Er B	
	K (mL/min/mg) × 10 ⁻²	q _o (mg/g)	K (mL/min/mg) × 10 ⁻²	q _o (mg/g)
	20	8.28	7.85	9.6
25	5.30	9.35	6.47	10.0
30	6.05	11.06	5.60	10.98

Column study

The column adsorption process generally shares advantage over batch operation. The observed data fit to the linearised form of the Thomas model^{29,30} and are given in equation (14):

$$\log(C_o/C_e - 1) = Kq_oM/Q - KC_oV/Q \quad \dots(14)$$

where C_o and C_e are the influent and effluent dyes (MB and ErB) concentrations (mg/L), respectively. K stands for the Thomas rate constant (mL/min/mg), q_o is the maximum solid phase concentration of solute (mg/g), M is the mass of the adsorbent (g), and V is the throughput volume (mL/min). The values of K and q_o are computed from the slope and intercept of the linear plot of log(C_o/C_e-1) versus V.

The effect of initial influent concentration was investigated using synthetic dye solutions containing 20, 25 and 30 mg/L of dyes (MB and ErB). The retention of dyes (MB and ErB) by the column gradually declines as the bed volume increases. To test different initial concentrations, the values of K and q_o are computed from the slope and intercept of the linear plot of log(C_o/C_e-1) versus V and they are entered in Table 5. The rate constant K,

decreased with the increase of the initial concentration of dyes. The q_o increased with the increase of the initial concentration of dyes (MB and ErB). When the PSLW carbon was saturated with dyes (MB and ErB), the MB and ErB were eluted with 500 mL of ethanol and 0.1 mol L⁻¹ NaOH respectively. Thus, column analysis data are practically useful in designing fixed bed columns on large scale.

Desorption study

Desorption of the adsorbed MB and ErB dyes were carried out using 0.1 N HCl, 0.1 N NaOH, CHCl₃ and ethanol. The per cent desorption for MB was found to be 58, 14.29 and 64.1 respectively with CHCl₃, 0.1 N HCl and ethanol; for ErB the per cent desorption was 22.1, 38.56, 7.28 and 26.8 respectively with 0.1 N HCl, 0.1 N NaOH, CHCl₃ and ethanol.

Comparison of MB and ErB with different adsorbents

The comparison of adsorption capacity of the various adsorbents for the removal of MB and ErB is given in Table 6. It shows that PSLW carbon studied in the present work has comparable adsorption capacity with that of the reported adsorbents.

Table 6 — Comparison of adsorption capacity of PSLW carbon with different adsorbents.

Dye	Adsorbent	Adsorption capacity, q (mg/g)	Reference
Methylene blue	Tea seed shell activated carbon	324.7	31
	Activated carbon (from textural waste)	32.36	32
	Waste paper activated carbon	68.03	33
	Screw pine leaves activated carbon	387.60	34
	Used tires activated carbon	30.21	35
	Neem leaf powder activated carbon	401.6	36
	PSLW carbon	25.06	Present study
Erythrosine B	Montmorillonite	578.03	37
	sugarcane bagasse	500	16
	PSLW carbon	22.88	Present study

The adsorption capacity varies and it depends on the characteristics of the individual adsorbent, the extent of surface/surface modification and the initial concentration of the adsorbate.

Conclusion

The present study shows that PSLW carbon is a very promising low cost adsorbent for the effective removal of dyes (MB and ErB) from aqueous solution. Equilibrium data of both dyes (MB and ErB) fits well with Langmuir isotherm. From the thermodynamic studies it is inferable that the adsorption of dyes (MB and ErB) on PSLW carbon is spontaneous, exothermic and thermodynamically favorable at low temperature. The kinetic data agrees very well with the pseudo second order rate equations with multi step intra particle diffusion model. In the column study, Thomas model is effectively used to predict removal of dyes (MB and ErB). From the results it is concluded that the adsorption of dyes (MB and ErB) onto the surface involves a faster rate as well as the slow diffusion of molecules through internal sites. Thus, application of this PSLW carbon may be highly useful in designing the cost effective and highly efficient technique for textile industrial effluent treatments.

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